Common Goods & Distribution

Public Finance and Environmental Policy in an Unequal World

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Abstract

Tax policy in the 21st century faces three key challenges: mitigating inequality, the possibility of high levels of global warming through the unregulated release of greenhouse gases into the atmosphere and a lack of investment in infrastructure. Global warming and underfinanced infrastructure are a consequence of mismanaged common goods. This thesis argues that policies regulating the use and the supply of these common goods can also have beneficial effects on the distribution of wealth and income.

For that purpose I analyze the distributional effects of different policy designs which regulate the use and supply of common goods. The thesis consists of two parts each corresponding to one common good:

In the first part, I study policies that manage the common good of the atmosphere in its function as a carbon sink and their distributional impacts. Such climate policies can affect poor households disproportionally since they spend a higher share of their income on carbon-intensive subsistence goods. The overarching research question in Part I is: *how can climate policies be designed such that they are distributionally neutral or progressive?* In this context I also discuss the following, more general question: *to what extent can interactions between public and climate policies enhance welfare?*

Part II of this thesis focuses on infrastructure in a broad sense including transport and energy infrastructure as well as investment in the education sector. Infrastructure is of major importance for an economy's growth trajectory, but also underfinanced in large parts of the world. I therefore analyze the equity and efficiency impacts of different financing mechanisms for public investment in infrastructure. The main research question is: *how can public investment in infrastructure be financed to be distribution-neutral or even inequality-reducing?* I further use a model in which wealth is disaggregated into physical capital and land, and in which households differ in the strength of their savings motive, to answer the following question: *which combination of wealth-based taxes can reduce inequality without harming efficiency?*

This thesis analyzes different design options for policies that regulate common goods in terms of their equity and efficiency implications. The main finding of this thesis is that, when equity considerations are included in the assessment of policies which regulate common goods, these policies can be designed to be distribution-neutral or even progressive. It thus provides additional reasons for implementing stricter common good policies, such as a higher carbon price and increased public investment in infrastructure. It further argues that accounting for interactions between public and climate policies is needed for a sound appraisal of second-best policies. Finally, this thesis demonstrates that wealth inequality can be reduced without harming economic output.

Zusammenfassung

Drei der wichtigsten politischen Herausforderungen für Finanzpolitik im 21. Jahrhundert sind: die Reduzierung von Ungleichheit, globale Erwärmung durch den unkontrollierten Ausstoß von Treibhausgasen in die Atmosphäre und ein Mangel an Investitionen in Infrastruktur. Eine zu hohe Konzentration von Treibhausgasen in der Atmosphäre sowie unterfinanzierte Infrastruktur sind eine Folge schlecht verwalteter Allmendegüter.

Die vorliegende Dissertation vergleicht verschiedene Politikentwürfe zur Regulierung der Nutzung und Bereitstellung von Allmendegütern und deren Wechselwirkungen mit Ungleichheit. Es wird gezeigt, dass Politikinstrumente zur Regulierung von Allmendegütern so gestaltet werden können, dass sie gleichzeitig die Ungleichheit verringern. Die Dissertation besteht aus zwei Teilen die jeweils einem Allmendegut entsprechen.

In Teil I untersuche ich die Verteilungswirkungen von Politikinstrumenten zur Regulierung der Nutzung der Atmosphäre als Senke für CO_2 Emissionen. Klimapolitik kann arme Haushalte stärker treffen als reiche Haushalte, da erstere einen höheren Anteil ihres Einkommens für CO_2-intensive Güter ausgeben. Die Forschungsfrage in Teil I ist daher: *Wie kann Klimapolitik konzipiert werden, so dass sie verteilungsneutral oder progressiv wirkt?* Außerdem diskutiere ich, in wie weit Wechselwirkungen zwischen Wirtschafts- und Umweltpolitik die Kosten von Umweltpolitik senken können.

Teil II behandelt das Thema der öffentlichen Finanzierung von Infrastruktur. Öffentliche Transport-, Energie-, Kommunikations- und Bildungs-Strukturen sind äußerst relevant für das Wirtschaftswachstum. Allerdings liegen die jährlichen Investitionen in Infrastruktur deutlich unter dem optimalen Niveau. Der zweite Teil befasst sich daher mit folgender Forschungsfrage: *Wie können öffentliche Investitionen so finanziert werden, dass die Ungleichheit verringert wird, oder zumindest unverändert bleibt?* Darüber hinaus untersuche ich die Frage ob Steuern, die nur auf bestimmte Vermögenskomponenten erhoben werden (wie z.B. auf Landrenten oder Erbschaften), die Ungleichheit senken können, ohne der Wirtschaft zu schaden.

Die vorliegende Dissertation zeigt auf, dass Politikinstrumente, die die Nutzung und Bereitstellung von Allmendegütern (wie der Atmosphäre und Infrastruktur) regulieren, so konzipiert werden können, dass sie Ungleichheit verringern oder unverändert lassen. Die Reduzierung von Ungleichheit kann deshalb eine zusätzliche Motivation darstellen für strengere Klimapolitik und gesteigerte Investitionen in Infrastruktur. Darüber hinaus wird gezeigt, dass Wechselwirkungen zwischen Wirtschafts- und Umweltpolitik die Kosten von Umweltpolitik deutlich verringern können, und dass Vermögensungleichheit reduziert werden kann, ohne dadurch die Wirtschaftsleistung einzuschränken.

Contents

Chapter 1

Introduction

The global economy relies on the use of many common goods. Examples include stocks of natural capital such as the atmosphere or fish in international waters and stocks of physical capital such as schools and energy and transport networks. The efficiency impacts of policies that regulate common goods have been studied in great detail already. The distributional effects of such policies, however, are under-researched. Hence, the main goal of this thesis is to compare different designs for policies that regulate common goods in terms of their impacts on inequality.

In general, common goods are defined as being non-excludable, but rivalrous. That is, it is difficult to restrict access to the good and one person's use of the good can impede another person's use of that good (for instance, through congestion or overuse). However, there is a fundamental difference between common goods that take the form of natural and those that take the form of physical capital: Natural capital is already there in the first place, if it is used at a sustainable rate, it is available to future generations. Physical capital, on the other hand, is built up over time and requires regular investment so that it will be available to future generations.

Leaving common goods unmanaged can lead to their deterioration via two main pathways: First, in the case of natural capital, individuals have an incentive to overuse the unregulated resource, an effect which is known as the *Tragedy of the Commons* (Hardin, 1968). Second, if the common good consists of physical capital, investment in such a good tends to be too low (Bom and Ligthart, 2014; Estache and Fay, 2007; Romp and Haan, 2007). Jakob and Edenhofer (2014) argue that from a welfare perspective, preventing overuse of natural capital and the underprovision of physical capital is a central task of public policy.

Public policy that regulates common goods changes the level at which these goods are supplied. This does not only affect an economy's efficiency but also the distribution between different households within the economy. The fact that inequality has been on the rise over the past 30 years in most OECD countries has lead to a growing interest in the drivers of this development and in the assessment of the distributional effects of different policies. This concerns both, inequality in income (OECD, 2011, 2015b), and in wealth ownership. Wealth is increasingly concentrated at the top of the income distribution in several developed countries (Piketty, 2014; Piketty and Zucman, 2014) and CEO pay has increased dramatically since the 1970s (Frydman and Saks, 2010).

A recent report by the OECD on pro-growth policies advises governments to give priority to equity-enhancing policies when choosing between policy options (OECD, 2015a). Thus there is a demand for assessments of the distributional effects of different types of public policies.

The topic of the present thesis is hence the interaction between inequality and policies that regulate the use and the supply of different common goods. The main focus lies on the equity and efficiency effects of different policy designs for carbon pricing and public investment in infrastructure. Furthermore, I also analyze the efficiency consequences of policies for inequality reduction. This thesis assesses the effect common good policies have on the intragenerational distribution, that is, on the distribution between households at a given point in time. The results provide additional reasons for investment in infrastructure and increased carbon taxes that prevent overuse of the atmosphere as a carbon sink.

In this thesis, I refer to infrastructure and the atmosphere as *common goods*. A common good, in contrast to a public good, is rivalrous: Infrastructure can be congested and the atmosphere in its function as a carbon sink can be used beyond its capacity to regenerate. In both cases, one person's use of the common good affects or impedes another person's use of that good – hence it becomes rivalrous (see Perman, 2003).[1]

Overview and methods

This thesis is divided into two main parts. Each part corresponds to a common good. Part I is dedicated to the atmosphere and Part II to infrastructure. In Sections 1.2 and 1.3 the background behind the individual common goods and their relation to inequality is discussed and the methods used are described.

The equity and efficiency effects of policies that regulate the use and provision of common goods occur through different channels. In each part of this thesis I focus on the channels which I consider the most relevant for the respective problem: Carbon taxes in developed countries affect low income households more strongly than high income households, due to the existence of a subsistence level of carbon-intensive goods. Since this effect mainly occurs in the short run, Part I focuses on income inequality and assumes heterogeneity in skill levels and the existence of a subsistence level of carbon-intensive goods.

By contrast, investment in infrastructure has mid- and long-term distributional effects, since it takes time for physical capital to accumulate, and depreciation of physical capital is rather slow. Hence Part II concentrates predominantly on the wealth distribution and household heterogeneity in saving behavior and time preference. For this purpose, I develop an intertemporal

[1] There are several equally valid terminologies when it comes to common goods: Kaul et al. (1999) refer to such goods as *impure global public goods*. Impure, because these goods can be rivalrous, and global, because, in most cases, they extend beyond the borders of individual countries. Uzawa (2005) uses the umbrella term *social common capital* for common goods such as natural capital and infrastructure.

model of heterogeneous saving behavior. In the last chapter of Part II, Chapter 7, I analyze long-term wealth concentration through bequests in a model in which wealth is disaggregated into physical capital and land, and in which I distinguish between bequest and life-cycle saving. For that purpose I focus on heterogeneous preferences for bequests as the main source of household heterogeneity. In all chapters, except for Chapter 4, which makes a conceptual argument, small to medium-sized general equilibrium models are used. These models are either solved analytically (Chapters 2 and 5, and partially in Chapter 7), or by numerical optimization (in Chapters 3, 6 and 7).

Main findings

This thesis answers the following questions: First, what are the distributional impacts of different designs of carbon tax reforms and infrastructure policies? Second, how should regulations of common goods be designed in order for them to reduce inequality (or at least be distribution-neutral)? Third, if reducing inequality is a policy goal in itself, which policies have the potential to enhance equity without harming growth?

Concerning carbon taxation, I demonstrate in Chapter 2 that the potentially regressive effects of carbon taxes can be offset by the recycling of its revenues. In Chapter 3 this result is generalized by considering more revenue recycling schemes and more channels through which carbon taxes act on the distribution. I argue in Chapter 4 that considering climate and public policy in a joint framework might reduce the cost of climate policy.

The equity and efficiency effects of infrastructure investment are analyzed in Chapters 5, 6 and 7. In Chapter 5, I show that capital taxes can indeed increase efficiency and reduce inequality at the same time, if the revenues are invested in infrastructure. In Chapter 6, capital, labor and consumption taxes are compared as a means to finance infrastructure – I demonstrate that capital taxes provide the most equal outcome but increase the efficiency only moderately. Labor and consumption taxes are more efficiency-enhancing but labor taxes increase inequality significantly. In Chapter 7, I relax the assumption of the previous chapters that wealth equals capital by differentiating between different components of wealth. I then compare different wealth-based taxes and find that there is scope for reducing wealth inequality without reducing output, even if the tax proceeds are not spent on public investment.

Structure of the Introduction

The remainder of the introduction is structured as follows: Since economic inequality is the leading topic in this thesis, in Section 1.1 I review the empirical literature on wealth and income inequality, the drivers behind recent increases in inequality and the growth effects of high levels of inequality. I also comment on different policy proposals for reducing inequality.

In Section 1.2, the atmospheric disposal space for greenhouse gases as a global common good is discussed. I give an overview of the scientific background behind global warming as a result of an overused atmosphere and review the literature on the distributional effects of carbon taxes. I provide the motivation behind the research in Part I of this thesis and the methods used.

In Section 1.3, I develop the research question which motivates the study of the distributional effects of infrastructure investment. I give an overview of both the empirical and the theoretical literature and I describe the empirical observations that drive the specific model assumptions.

Section 1.4 lays out the objective and the structure of this thesis.

1.1 Economic inequality

In this section I present key findings from the recent literature on the development of inequality. I then discuss some of the drivers of this development and I introduce a set of "new stylized facts on growth and distribution" which emerge from this discussion. Finally I discuss some of the policy measures proposed to reduce inequality.

The topic of economic inequality is a recurring theme binding together all chapters of this thesis. Several influential books on the topic have been published in the last years (Atkinson, 2015; Piketty, 2014; Stiglitz, 2012) and reducing economic inequality is high on the political agenda of many countries. The reason behind this development is that economic inequality has been rising in recent decades in most developed countries.

Inequality in terms of income has increased in a majority of OECD countries over the last decades: Between the 1980s and the mid 2000s the Gini coefficient in income increased by almost 10% (OECD, 2011).[2] In the same time interval, the share of total income going to the top 1% in the U.S. has doubled (Alvaredo et al., 2013).

Increased wealth concentration in the top 1% or 0.1% is another key aspect of increasing economic inequality. Piketty (2014) and Piketty and Zucman (2014) show that the gap between the top 1% and the remaining 99% in terms of wealth ownership has been increasing dramatically in the last 30 years. For instance, Alvaredo et al. (2013) show that the share of capital income going to the top 1% (of the U.S. income distribution) increased in the period between 1980 to 2000 from 17% to 27%. This growing disparity also manifests itself through an increase in the wealth/income ratio from a value between 2 and 4 in 1970 to a value between 4 and 6 in 2010 in several countries (Piketty and Zucman, 2014).

The full extent of this increase in the wealth concentration is not perceived by the public: Norton and Ariely (2011), two behavioral economists, asked participants in an online survey to estimate the current wealth distribution in the U.S. and to state their idea of an ideal wealth distribution. The stunning result was that the participants on average largely underestimated wealth inequality. Furthermore, their ideas of an ideal wealth distribution, independent

[2]Note that at the same time, global income inequality has decreased (Milanovic, 2013). This is largely due to the accelerated economic development of populous countries such as China and India, which lifted millions out of poverty.

of their political background, were much more equal than the status quo.[3] Figure 1.1 illustrates the U.S. distribution of net wealth in 2008 based on Wolff (2010). The figure demonstrates that while the lowest 40% hardly own any wealth, the most wealthy 5% own 62% of total capital. The remaining 38% of net wealth belong to a middle income group which makes up 55% of the population.

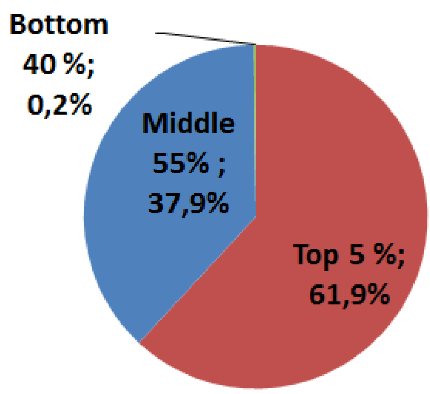

Figure 1.1: U.S. distribution of private net wealth. This figure is based on Wolff (2010).

Economic inequality is not necessarily negative: If hard-working individuals receive a higher compensation than less diligent ones, inequality in *returns to efforts* provides a strong motivation for working harder. If, by contrast, inequality is caused by factors beyond an individual's personal responsibility the inequality is in *opportunities* (Roemer, 1993). High inequality in returns to efforts increases the growth rate, while high inequality of opportunity has been found to decrease it (Marrero and Rodríguez, 2013). In the U.S., the level of inequality of opportunity is among the highest levels in advanced countries (Stiglitz, 2012). High levels of inequality of opportunity are usually coupled to a low social mobility – thus enhancing the concentration of wealth further. This effect is know as the *Great Gatsby Curve* (Corak, 2013).

However, high levels of inequality can affect the economic efficiency through a variety of channels. Inequality can impact growth directly, for instance by influencing the duration of periods of high growth (Berg and Ostry, 2011; Berg et al., 2012) or by increasing the risk of economic crises (Kumhof et al., 2015). It can also affect growth through more indirect channels, for example by enhancing the risk of civil conflicts (Cederman et al., 2011; Ostby, 2008; Ostby and Strand, 2013), or by affecting health negatively (Lund et al., 2010; Wilkinson and Pickett, 2009).[4] Additionally, Burkhauser et al. (2015) demonstrate that there is a significant negative correlation between the income share going to the top 1% and different indicators of well-being.

[3] Participants in the survey were chosen from a nationally representative panel.

[4] Note that some of the findings by Wilkinson and Pickett (2009) are heavily debated in the literature (Noble, 2009; Liebig, 2012).

Drivers of increased economic inequality

For Piketty (2014) the increase in wealth inequality is the consequence of a fundamental law of capitalism itself: Whenever the interest rate r exceeds the growth rate of the economy g, total wealth of households at the top of the wealth distribution grows faster than total income. The author backs this claim with a convincing analysis of huge economic data sets of several developed countries dating back as far as the 18th century.

Piketty's argument can be criticized from several viewpoints: First, it relies on the assumption that wealthy households save all of their income. If they only save a fraction s of their income (which is very likely), the condition for increasing wealth inequality would be $sr > g$, not $r > g$ (Stiglitz, 2015e) – which is less likely to be met.[5] Second, if more and more capital is available, standard neoclassical theory tells us that the returns to capital should decrease, thus discouraging further investment in capital (Milanovic, 2014a). Rognlie (2014) expands this argument by deriving the net elasticity of substitution between capital and labor that corresponds to r remaining constant in the face of an increase in the wealth income ratio. He shows that the elasticity of substitution assumed by Piketty by far exceeds the empirical estimations of that parameter.[6] Third, a large part of the increase in the wealth/income ratio in several countries has been driven by increases in the value of housing and land (Rognlie, 2014; Homburg, 2015, see also Figure 1.2). By equating capital with wealth (including land), Piketty does not reflect this important finding in his theoretical framework – this might, at least partially, explain the missing reaction of the interest rate to the increase in the wealth/income ratio.[7]

Other drivers of the increasing gap between rich and poor households seem to be of at least equal or higher importance: First, the share of income going to labor is declining in OECD countries. The average labor share dropped from 66.1% in the early 1990s to 61.7% in the late 2000s (OECD, 2012). Second, even though average worker productivity has doubled since the 1970s, wages for low- and middle income households hardly increased (Mishel et al., 2015). While the income of the bottom 99% in the U.S. grew by 0.6% annually since the mid-seventies, the income of the top 1% grew by 4.4% (Atkinson et al., 2011; Piketty et al., 2014). Third, recent publications suggest an increase in economic rents going to the top percentiles of the income distribution (see e.g. Stiglitz, 2015b and Stiglitz, 2015e). An economic rent is a return on a factor which exceeds the opportunity cost of providing that factor (Dwyer, 2014). Among other sources, rents originate through scarcity, by exercising political influence or by exploiting market power. For instance, resource owners can

[5] For estimates of high income households' saving rates see e.g. Dynan et al. (2004) and Saez and Zucman (2015).

[6] There are frameworks in which the interest rate (and with it total capital accumulation) depends only on the preferences of one class of households – however, such frameworks are not employed by Piketty. One example would be models in which a version of the Pasinetti (1962) paradox occurs: In such models the long-term interest rate depends only on the preference parameters of the high income class (and potentially, the capital tax rate). I analyze such models in Chapters 5 and 6 of this thesis.

[7] Another line of critique comes from Acemoglu and Robinson (2014). The authors claim, among other things, that Piketty largely neglects the role of institutions in his works. Milanovic (2014b) analyzes their arguments and finds, however, that some of them do not hold.

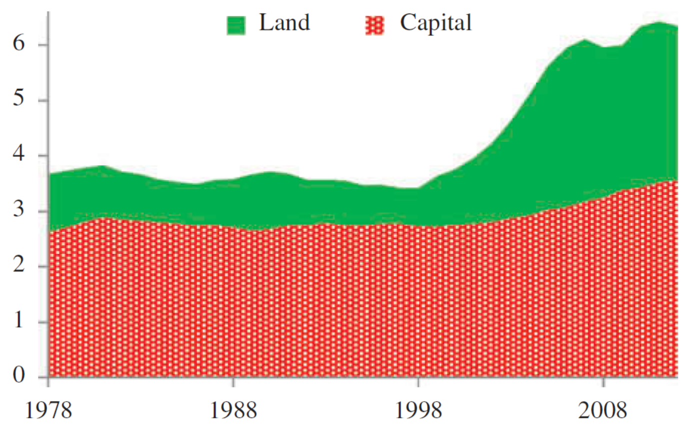

Figure 1.2: Wealth/income ratio between 1978 and 2008 for the case of France. Figure adapted from Homburg (2015) under the Creative Commons Attribution License.

sell their resource above its extraction costs if the resource is scarce.[8] Stiglitz (2015e) argues that many of the rents that significantly contribute to rising inequality accrue in the financial sector. For example, rents that are created through predatory lending practices, insider trade and high-frequency trading.[9]

Stiglitz (2015e) further points out that many of these inequality-increasing developments occurred as a response to changes in policies instead of an inherent dynamic of capitalism. Additional evidence is presented by Piketty et al. (2014) who find a strong link between a surge in CEO pay and a drop in the top income rates since 1960. They show that, for the case of the U.S., low tax rates are correlated with an increase in the share of CEO pay that is not directly related to the CEO's performance. Finally, their results suggest no correlation between the drop in top income rates and the growth rate. The initial motivation for reducing top income rates – that is reducing the burden on high income households such that they get wealthier with some of their wealth subsequently "trickling down" to less wealthy households – appears to be invalidated by Piketty et al. (2014)'s results. Despite these findings, reducing taxes to spur business activity is still high on the political agenda of many U.S. Republicans (Bush, 2015).

New stylized facts of economic growth

Most of these empirical insights on inequality and the return on capital, outlined above, cannot be explained by standard economic theory. Stiglitz (2015a,b,c,d) recently put forth a series of four working papers in which he summarizes these insights in five points which he calls the *new stylized facts of economic growth*. These stylized facts are: (i) inequality in labor and capital income is growing, (ii) the wealth distribution is more unequal than the

[8]For a thorough analysis of the distributional impacts of rents in the context of climate policy see Mattauch (2015).

[9]Why are these rents not competed away, especially in the banking sector? Azar et al. (2016) provide at least a partial answer. They show that in the U.S., the shareholders of some of the biggest banks are identical. The authors show that common ownership and also cross ownership (banks holding shares of other banks) are strongly correlated with higher banking fees.

labor income distribution, (iii) even though productivity increases, average wages have stagnated (and hence the capital share has increased), (iv) the wealth/income ratio has increased significantly, and, (v), the return to capital has not declined as a response to (iv).

To explain these facts, Stiglitz proposes a new set of models in which generic *capital* is divided into land and capital and heterogeneous saving behavior is a key difference between households. I recognize the importance of these insights and further develop these tools in Part II of the present thesis: In Chapters 5 and 6, I use a model of households that differ in their saving behavior and I account for endogenous saving rates which react to policy changes. In Chapter 7, when analyzing different instruments for reducing wealth inequality, I explicitly divide wealth into physical capital and land, and I distinguish between life-cycle and bequest saving.

Measures against inequality

Policies that have the purpose to alleviate inequality directly have long been thought to reduce economic efficiency (Okun, 1975). Kaldor (1955), for instance, argues that taxing the rich reduces capital accumulation (which in turn reduces growth), since rich households have a higher saving rate. Based on this reasoning, top income tax rates have been reduced in most developed countries in the last third of the 20$^{\text{th}}$ century. The effect of this type of policy on growth, however, has been negligible (Piketty et al., 2014), while the impact on inequality was huge (Piketty et al., 2014; Piketty and Zucman, 2014; Saez and Zucman, 2015).

As a measure to counter the prevailing trend of increasing inequality, Piketty (2014) proposes a progressive capital tax, based on a model study by Piketty and Saez (2013). However, one of the most important insights in the optimal taxation literature is that the optimal capital tax level is zero (Chamley, 1986; Judd, 1985; Atkinson and Stiglitz, 1976). Nevertheless, Piketty and Saez (2013) derive optimal capital tax rates between 50-60% for a model calibrated to the U.S. and France. The main driver of the non-zero optimal capital tax is the fact that households in their model have heterogeneous preferences for leaving bequests (Piketty and Saez, 2012). Modeling this type of heterogeneity explicitly is a credible assumption since differences in these preferences are a key determinant of wealth inequality (Cagetti and De Nardi, 2008).[10]

However, apart from efficiency reasons, there are also distributional reasons why the recommendation of an increased capital tax rate should be treated with caution: Stiglitz (2015c) demonstrates that under certain conditions, the burden of a capital tax can be shifted completely from capital to labor. A capital tax thus could even increase inequality. In a subsequent paper Stiglitz (2015e) argues that there is reason to believe that a major driver of increasing inequality has been the change in policies in the recent decades. Instead of taxing capital he recommends equity-enhancing public policies such as increasing public investment in education, reforming the bankruptcy law and

[10]Gale and Scholz (1994) show that intergenerational wealth transfers make up about half of the total capital formation. Accounting for bequest heterogeneity is likely to lead to arguments for a positive taxation of bequests (Kopczuk, 2013), which can nicely be seen in Piketty and Saez (2012).

taxing land rents and bequests.[11]

This thesis takes current inequality levels and the new stylized facts of distribution and growth (see page 7) as a starting point. Different designs for public policies are analyzed in terms of their equity (and efficiency) impacts: In Part I I focus on the short-term distributional impacts of climate policy. For that purpose I mainly concentrate on income inequality and skill heterogeneity. Part II of this thesis focuses on the long-term effects of different financing options for public investment on equity and efficiency. The aim of both parts of this thesis is to determine efficient public policy designs (either for the purpose of climate protection or of increasing public investment) that are either distribution-neutral or progressive.

1.2 The atmosphere as a common good

The atmosphere, in its function as a sink for greenhouse gases, constitutes a common good: In the absence of policy, nobody can be excluded from using the atmosphere as a carbon sink. However, one person's use of it does inhibit another person's use when the sink is used beyond its regenerative capacity.[12] This specific common good is of major importance when it comes to the topic of global warming: If too much carbon is released into this sink too fast, the global climate will heat up beyond sustainable levels. The 2015 United Nations Climate Change Conference COP 21 successfully negotiated a global agreement to limit global warming below 2°C compared to pre-industrial levels (UNFCCC, 2015).

To maintain warming levels below this threshold, the use of the atmosphere as a carbon sink has to be regulated by some form of climate policy. A major concern about climate policies, however, is that poor households are affected disproportionally hard, since they spend a higher share of their income on carbon-intensive goods such as food, heating and electricity. This concern is among the biggest political obstacles to introducing a carbon price (Combet et al., 2010; Ekins, 1999). Further, there are hardly any theoretical studies

[11] Stiglitz's intuition is confirmed in Chapter 7, where I show that, even with heterogeneous preferences for bequests as in Piketty and Saez (2013), it is more efficient to tax land rents and bequests separately, instead of aggregate capital. A similar idea has already been developed by Henry George (1879/2006), who proposed a 100% tax on land rents on grounds of equity and efficiency. He considered a land tax to be a non-distortionary way of raising revenue. Feldstein (1977), however, discovered that a tax on land rents can indeed be distortionary, for example by inducing a shift in the portfolio of investors (if they hold more than one asset). Edenhofer et al. (2015b) show that such a "portfolio effect" can be beneficial if there is an underaccumulation of private capital. In a follow-up article, the authors find similar beneficial effects when considering fossil resources as a fixed factor to be taxed, instead of land (Siegmeier et al., 2015). Mattauch et al. (2013) demonstrate that financing public capital through land rent taxes is superior to other financing mechanisms in a modern neoclassical framework, due to their non-distortionary character. Thereby they translate an earlier result by Arnott and Stiglitz (1979) dubbed the "Henry George Theorem" to a macroeconomic scale: In cities of optimal size, aggregate land rents equal the expenditure on a public good.

[12] A stable climate or climate change mitigation are both public goods. This is not the case, however, when looking at the atmosphere as a sink for greenhouse gases, which is used beyond its regenerative capacities.

that model the effect of carbon taxes on the within-country distribution when heterogeneous households must consume a minimum level of carbon-intensive goods. This motivates the studies in Chapters 2 and 3 of Part I of this thesis in which I determine the distributional effects of different designs of carbon tax reforms when households must consume a minimum level of CO_2-intensive goods. Specifically, I answer the question: *How can a carbon tax reform be designed such that it is distribution-neutral or progressive?*

Another obstacle to introducing climate policy are the short-term costs associated with it: Since the benefits of avoided climate damages accrue largely in the future, policymakers hesitate to take immediate action. In Chapter 4 of Part I, I demonstrate that, if climate and public policy are analyzed in a joint framework, there exist beneficial policy interactions that potentially reduce the short-term costs of climate policy significantly.

Global warming: background

The global mean temperature results from the difference between (unreflected) incoming solar energy and outgoing thermal energy (IPCC, 2013). Changes in the concentration of greenhouse gases (most importantly CO_2, but also others like methane and nitrous oxide) in the atmosphere lead to a change in the earth's ability to emit thermal radiation into space: An increased concentration reduces the earth's emission of thermal radiation. This leads to an increase in the global mean temperature (IPCC, 2013).

A rapidly warming climate has several adverse effects. Over the period between 1850 and 2012, the global mean surface temperature increased by 0.89 °C (Stocker et al., 2013, 2.2). This was accompanied by a rise in the global mean sea level by 19 centimeters in the period between 1901 and 2010 (Stocker et al., 2013, 2.6). If emissions of all greenhouse gases would be stopped immediately, this trend would still continue due to inertia in the climate system: The global mean temperature would continue to rise over the course of the 21st century by 0.6 °C compared to the year 2000 (IPCC, 2013, FAQ 12.3). However an immediate emissions stop is impossible.

Model studies predict an additional temperature increase between 0.3-1.7 °C for a low and 2.6-4.8 °C for a high emissions scenario until the end of the century, relative to the reference period of 1986-2005 (Stocker et al., 2013, Table TS.1). Sea levels are predicted to rise an additional 26 to 55 centimeters in a low and 45 to 82 centimeters in a high emissions scenario, relative to the reference period 1986-2005 (Stocker et al., 2013, Table TS.1).[13] Furthermore, a warmer climate also leads to an increase in extreme weather events (Stocker et al., 2013, 2.7), water scarcity and to a shift in monsoon patterns (IPCC, 2013, 12.5.5.8). This could lead to a decrease in food security (IPCC, 2014a, 7.2 and to large subsequent migration flows IPCC, 2013, 12.4).

The problem of global warming will not be solved because humanity runs out of fossil resources: A substantial part of the fossil resources known today has to remain under ground in order to achieve ambitious climate goals. Jakob

[13] Church et al. (2013) argue that these estimates are quite conservative: A potential collapse of the part of Antarctic ice sheet that has bases below sea level was not taken into account due to relatively high insecurities. In the case of a potential collapse estimates would be several tenths of a meter higher.

and Hilaire (2015) calculate that, if global warming should be limited to 2°C, 80%, 50% and 30% of all current coal, oil and gas reserves, respectively, have to remain unused (Figure 1.3 translates these percentages to gigatonnes CO_2).

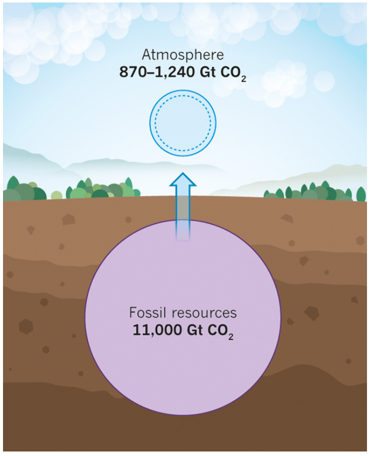

Figure 1.3: Fossil fuel resources exceed atmospheric disposal space for carbon emissions. Reprinted by permission from Macmillan Publishers Ltd: Science (Jakob and Hilaire, 2015), copyright 2015.

The target of limiting global warming to less than 2°C compared to pre-industrial levels, reaffirmed at the COP 21 conference, hence corresponds to a limit on the amount of greenhouse gases which can be released into the atmosphere. The most cost-effective way to reach this target is by pricing CO_2 and CO_2-equivalent emissions (Tietenberg, 1990) – the common good of the atmosphere would thus ideally be regulated by a pricing mechanism. Such a mechanism provides the right incentives to abate emissions where this can be done in the most cost-effective way. This policy would induce a transformation of the energy and production sectors towards a greener economy.[14]

Obstacles to environmental policy: the distribution of costs

Even though it is widely recognized that pricing emissions is the most cost-effective instrument for reducing global warming, there are major obstacles that mainly concern the distribution of costs on three different levels: between countries, between different generations and between individuals within countries.

First, some countries, like the U.S. and Great Britain, have been emitting large amounts of CO_2 already since the mid 18th century. Others, like China, only started to contribute significantly in the second half of the 20th century. Data on economic development and CO_2 emission trajectories of various countries suggests that there are strong links between the two, especially in the early stages of development (Edenhofer et al., 2014; Maddison, 2007). Putting a uniform global price on carbon could hence interfere with economic development,

[14] Pricing emissions can also be interpreted as restricting the access to the formerly open-access resource of the atmospheric disposal space for greenhouse gases. Edenhofer et al. (2012) analyze the climate problem from this viewpoint. They highlight the difficulties associated with restricting access to the atmospheric disposal space and discuss possible ways to alleviate these difficulties.

especially in countries that still are in the early stages of economic development. Depending on country-specific factors such as damages and abatement opportunities, some of these countries might have less incentives to price carbon than countries that are already fully developed. There is a whole strand of predominantly economic literature which analyzes the issue of how global climate treaties can be designed such that participation in a global climate agreement is enhanced (see, for instance, Barrett, 1999; Carraro and Siniscalco, 1993; Kornek, 2015).

The second obstacle is the intergenerational distribution of costs: If current generations invest in mitigation now, they might have to reduce their consumption levels. The benefits of these mitigation efforts, however, accrue in large parts in the distant future – to generations which are yet to be born (Foley, 2008).[15] A large body of literature analyzes different types of intergenerational transfer mechanisms to design Pareto-improving climate policies, that is, climate policies which make at least one generation better off without harming other generations. These transfer mechanisms include diverting investment away from capital towards mitigation (Rezai et al., 2012), changes in the prices of fixed assets which are traded among generations (Karp and Rezai, 2014; Schultes et al., 2015) or financing mitigation through debt (Bovenberg and Heijdra, 1998; Heijdra and Bovenberg, 2002). Some of this literature is reviewed in more detail in Section 4.3.6. Instead of focusing on Pareto improvements, a parallel strand of the literature focuses on determining socially optimal climate policies by comparing the benefits of avoided climate damages with the total cost of climate policies numerically with large integrated assessment models (*cost-benefit analysis*). This approach has been pioneered by Nordhaus (1994) with the DICE model. These models usually feature one (or several) infinitely-lived agent(s) and are based on the Ramsey-Cass-Koopmans model (Ramsey, 1928; Cass, 1965; Koopmans, 1965). Within such frameworks the utility of future generations is discounted by the pure rate of time preference (PRTP) (Arrow et al., 2013). This lead to unresolved debates on how the PRTP is calibrated correctly.

Stern et al. (2006) determines the PRTP based on normative choices (the so-called *prescriptive* approach) and arrives at a very low optimal PRTP and hence a very high optimal carbon price. Nordhaus (2007), by contrast, calibrates the PRTP to the observed market interest rate (the so-called *descriptive* approach). However, around half of the total saving is life-cycle motivated, a motive which is absent in the Ramsey-Cass-Koopmans model – Nordhaus' discount rate is hence too high, which results in a too low weight on future generations' utilities and an optimal carbon price that is an order of magnitude lower than the optimal carbon price determined by Stern et al. (2006). Saving motives are described in more detail in Section 1.3 and are the leading source of heterogeneity in Part II of this thesis. The shift in focus towards Pareto-improving policies avoids debates on the calibration of the PRTP.

[15] However, even if countries only act in their national self-interest, Edenhofer et al. (2015a) demonstrate that side-benefits, occurring through carbon pricing, can incentivize these countries to implement stricter climate policies. This even applies when policymakers in these countries have to operate under short-term political constraints, since many of these side-benefits manifest on much shorter timescales than climate change. An example of such a short-term side-benefit is reducing air pollution, which is the single largest environmental health risk in Europe nowadays, leading to more than 400000 premature deaths in 2012 (EEA, 2015).

The third obstacle concerns the intragenerational distribution within individual countries: Climate policies, especially a carbon tax, raise concerns about their potentially high burden on low income households. In developed countries, a carbon tax is expected to increase the prices of carbon-intensive subsistence goods such as heating, food and electricity (Fullerton, 2011; Grainger and Kolstad, 2010).[16] Low income households spend a large part of their income on these subsistence goods and are hence affected disproportionally hard by carbon pricing (Combet et al., 2010; Flues and Thomas, 2015; Levinson and O'Brien, 2015). [17] Furthermore, there are also employment effects which can affect the intragenerational distribution negatively, since a disproportionally high share of low skilled workers are employed in pollution-intensive sectors of the economy (see, for instance, Babiker and Eckaus, 2007; Fullerton, 2011; Schwerhoff and Franks, 2016). These effects, however, are beyond the scope of the current thesis. In Chapters 2 and 3 I examine the intragenerational distributional effects of climate policy.

Prior work on the intragenerational distributional effects of climate policy

The potentially regressive effect of carbon pricing sparked a discussion about how a carbon tax reform, that is, a carbon tax combined with a mechanism to redistribute the tax revenues, should be designed to avoid placing a disproportionate burden on low income households. For instance, the Citizens' Climate Lobby, an environmental movement supported by the influential climate scientist James Hansen, promotes a specific carbon tax reform design which they call "fee and dividend" (The Guardian, 2010; CCL, 2016). The "fee and dividend" carbon tax reform is revenue-neutral: A carbon fee is levied and all revenue is returned to the citizens through (monthly or annual) uniform lump-sum transfers.

The literature that analyzes the distributional effects of carbon tax reforms theoretically (in models with heterogeneous households) either relies on large numerical models (Rausch et al., 2010, 2011), or on relatively specific model assumptions (Chiroleu-Assouline and Fodha, 2011, 2014; Fullerton and Monti, 2013). There does not seem to be a consensus in how far a carbon tax can be made distributionally neutral or progressive by the recycling of its revenues: While it seems possible in the studies by Chiroleu-Assouline and Fodha (2011,

[16] Note that carbon as well as fuel taxation might not not have the same effect in developing countries (Shah and Larsen, 1992; Sterner, 2011). This is partially due to the continued use of biomass as a primary fuel of the very poor, who are not able to afford taxable fuels (Pachauri, 2004).

[17] The concept of the environmental Engel curve relates a household's income and the amount of pollution embodied in its consumption. Levinson and O'Brien (2015) find that in the U.S., the Engel curve is increasing in income but concave. They conclude that rich households consume more than poor households in absolute terms, but their consumption bundles are less pollution-intensive. Also for the case of the U.S., Grainger and Kolstad (2010) demonstrate that for some carbon-intensive goods such as electricity, heating and food, subsistence levels exist. According to their study, a price increase in these goods due to carbon pricing is the main driver behind the regressivity of this policy. Wier et al. (2001) confirm for the case of Denmark, that the main component of low income cohorts' spending are carbon-intensive necessities, while high income cohorts spend a higher fraction of their income on "luxury" items with a higher service component. They compare their study to similar studies of other developed countries, and find that their results still remain valid.

2014), Fullerton and Monti (2013) show that the recycling of carbon tax revenues might not be enough to offset the burden the tax places on low income households.

A related strand of literature analyzes a similar question in optimal taxation frameworks with heterogeneous agents: Should the optimal income tax rules be adjusted when a carbon tax is set to its optimal level? The answer depends on the availability of policy instruments to the government: The income tax rules should be adjusted if carbon taxes are linear and income taxes are non-linear, and if the government does not have access to uniform lump-sum transfers (Cremer et al., 1998). They should not be adjusted if both taxes are linear, or non-linear, or if uniform lump-sum transfers are available (Jacobs and De Mooij, 2015). Kaplow (2012) additionally takes distributional issues into account by constraining the government to distribution-neutral tax reforms. He shows that, starting from an arbitrary initial (commodity and income) tax system, Pareto improvements are possible by adjusting the taxes into the direction of the first-best tax system (without changing the distribution). Even though highly relevant, these findings are rather abstract and do not lead to major insights about the distributional impacts of a carbon tax reform in an optimal-taxation setting.

In Chapter 2, I analyze different designs for carbon tax reforms in a small analytical model. I explicitly model the fact that households need to consume a minimum level of CO_2-intensive goods. Among other designs, I also analyze a "fee and dividend"-type approach.

Chapter 3 builds on Chapter 2 but is a contribution to the optimal taxation literature: It complements this literature by determining the changes in the optimal (non-linear) income tax rates and the resulting change in inequality after an increase in the preference for environmental quality.

The leading topic of Chapter 4 is the level of the total cost of climate policy. By reviewing different studies which treat climate and public policy in an integrated framework, it is argued that the costs can be significantly lower due to the occurrence of beneficial policy interactions.

1.3 Infrastructure as a common good

Infrastructure is not only "an input into a growth optimizing game: it literally underpins civilized life" (Goldsmith, 2014, p.45). The physical capital stock of infrastructure tends to be undersupplied in the absence of policy – in the same way as mismanagment of natural capital stocks leads to their overexploitation. It hence is a central task of public policy, which aims at increasing welfare, to prevent both overuse and underprovision of common goods (Jakob and Edenhofer, 2014).

Even though there are some public investment policies in most countries, infrastructure is largely underprovided (Bom and Ligthart, 2014; OECD, 2007;

Romp and Haan, 2007). According to the World Economic Forum, the global gap in infrastructure funding is about 1 trillion US$ per annum (WEF, 2013).[18]

The concept of infrastructure used in Part II of this thesis is very broad: it includes transport and energy infrastructure, as well as other physical assets owned by the state, such as schools and libraries. These goods are non-excludable but they are subject to congestion, which makes them rivalrous – they are hence common goods. The aim of Part II is to analyze the long-term distributional effects of different financing options for infrastructure investment.

Is infrastructure underprovided?

The empirical literature largely agrees that infrastructure is underprovided: Aschauer (1989) was the first to estimate an output elasticity of public capital of 0.4 with public capital entering the production function. This relatively high value has been corrected downwards by later studies (see Gramlich, 1994; Bom and Ligthart, 2014 and the review in Calderón and Servén, 2014b). Most recently, Calderón et al. (2015) address several methodological problems of earlier approaches and estimate an output elasticity of infrastructure in the range of 0.07-0.10. Bom and Ligthart (2014) review a large number of studies from OECD countries and find a short-run output elasticity of public capital of 0.08 and a long-run elasticity of 0.12 (with an average elasticity of 0.11).[19]

It is concluded from these studies that public capital is undersupplied, since the average output elasticity of public capital from Bom and Ligthart (2014) implies a return to public capital of 0.24 (assuming that public capital amounts to around 50% of GDP in OECD countries; Kamps, 2006). This return exceeds the sum of an assumed depreciation rate of 10% and a (relatively high) interest rate of 4% by 10%. Even if, instead of the average output elasticity, the short-term elasticity is considered, the return to public capital is 16% – thus exceeding the sum of the depreciation and the interest rate by two percent.

Providing such high rates of return, increased investment in public capital should have a positive effect on growth (which it does, see e.g. the review in Calderón and Servén, 2014b). Several other aspects of infrastructure investment have been researched to a much lesser extent: For instance, the impact of infrastructure on health, on education and on equity. The availability of sanitation services greatly reduces health risks. Access to electricity and communication services boosts education possibilities (OECD, 2006). The impact of public infrastructure investment on equity is the main topic of Part II of this thesis.

The distributional effects of infrastructure investment

Most empirical studies find evidence for an inequality-reducing effect of investment in infrastructure (see, for instance, Calderón and Chong, 2004

[18]The authors calculate this gap in infrastructure financing from infrastructure spending data taken from the IHS Global Insight Construction Database and infrastructure-needs data from OECD (2007).

[19]This value increases to 0.19 if only core components of public capital that are provided at the regional level are considered.

and the review in Calderón and Servén, 2014a). According to the studies above, however, little is known about the magnitude of these effects (both on growth and inequality) and the underlying mechanisms through which public investment acts on these variables.

The theoretical literature on infrastructure investment has mainly focused on growth effects. Infrastructure investment is found to enhance growth (Agénor, 2013). However, it has decreasing returns to scale and raising revenue for financing infrastructure usually has adverse effects on growth.[20] There hence is a trade-off between the growth-enhancing effects of infrastructure and the detrimental effect of its financing which determines the optimal level of infrastructure provision (Barro, 1990). Further theoretical literature on the growth effects of infrastructure financing is reviewed in Agénor (2013) and Calderón and Servén (2014b).

Previous theoretical work, however, is inconclusive when it comes to the distributional effects of infrastructure investment: Alesina and Rodrik (1994) demonstrate that public investment which reduces inequality always decreases efficiency. Glomm and Ravikumar (1994) argue that in their model, no equity-efficiency trade-off occurs since public investment is distribution-neutral in the long run. Chatterjee and Turnovsky (2012) demonstrate that labor and consumption tax-financed public investment increases income inequality in the long run, while capital tax financing has the potential to slightly decrease it. They find that inequality in wealth and welfare is always enhanced in the long run independent of the financing mechanism.

Those studies use a very stylized concept of agent heterogeneity: Households differ only in their initial capital endowment. Alesina and Rodrik (1994) additionally account for heterogeneity in income sources. I argue that the type of household heterogeneity assumed crucially influences the distributional effects of public spending. In the subsequent paragraphs I review alternative concepts of heterogeneity which I consider to be most relevant when it comes to assessing the distributional effects of public spending.

Stylized facts on household heterogeneity

When looking at the U.S. distribution of net wealth (Figure 1.1 on page 5) it becomes apparent that (1) the bottom 40% hardly own any wealth, (2) wealth is strongly concentrated at the top, and (3) there exists a kind of middle-class which owns some wealth. What distinguishes these three cohorts?

In the following, I present three stylized facts on household heterogeneity which could explain a wealth distribution as depicted in Figure 1.1. First, wealthy households have a mainly bequest-motivated saving behavior and thus save dynastically, while middle income households save in large parts for life-cycle reasons (Attanasio, 1994; Dynan et al., 2004; Browning and Lusardi, 1996). Neither of these saving motives alone can reproduce the observed wealth distribution (Carroll, 2000). Second, wealthier households

[20] This might not be case if it is financed by rent taxation, see, for instance, Dwyer (2014); George (1879/2006); Mattauch et al. (2013).

are more likely to be self-employed and to receive more business and capital income than wage income (Quadrini, 1997; Diaz-Gimenez et al., 2011; Wolff, 1998). Third, wealthier households have been shown to have lower rates of time preference (Green et al., 1996; Lawrance, 1991). Krusell and Smith (1998) show that allowing for different time preference rates is crucial for reproducing the observed wealth distribution.

I explicitly model these heterogeneities for analyzing the distributional effects of public investment in Chapters 5 and 6. I account for endogenous saving rates as in Michl and Foley (2004) and Michl (2009), since they play an important role in determining the long-run distributional effects of public investment. In the model, a wealthy high income class is assumed to save dynastically, to have a higher time preference rate and to receive only capital income. This class is modeled as an infinitely-lived agent. A less wealthy middle income class saves for life-cycle purposes and is modeled as an overlapping generations agent.
Chapter 7 further analyzes two aspects from which I abstracted in Chapters 5 and 6: First, wealth consists of more than just physical capital. In fact, an important driver of the recent increase in the wealth/income ratio (see Piketty, 2014, and Piketty and Zucman, 2014) has been the land component of wealth (Homburg, 2015). Second, in Chapters 5 and 6 I only consider two polar cases of saving behavior: purely life-cycle motivated and purely dynastic. This stylized representation of heterogeneity in saving behavior allows for deriving important insights about the dynamics of wealth inequality and public investment – a more realistic approach, however, would be to consider households with different shares of life-cycle and bequest motivated components in their saving behavior.

In Chapter 7 I therefore use a model in which wealth is disaggregated into land and physical capital and in which households differ in the strength of their bequest motive. In that framework the distributional effects of financing public capital with different wealth-based taxes are analyzed.[21]

Outline of Part II

Part II of this thesis, the analysis of the distributional effects of public spending, is divided into three chapters:

In Chapter 5, I use a small analytical model to analyze how public spending, which is financed by a capital tax, influences equity and efficiency.

In Chapter 6, I generalize the framework used in the preceding chapter to more general functional forms and to include more possibilities for financing public investment in infrastructure, in particular labor income and consumption taxes. I also include further channels through which public investment affects the distribution of wealth, welfare and income.

[21] Apart from using the tax revenue for public spending, other recycling mechanism are analyzed such as lump-sum transfers to the households. In Chapter 7 the recycling mechanism does not have a big influence on the outcome in terms of distribution – it has an impact on total output, however.

In Chapter 7, I compare different wealth-based taxes in terms of their equity and efficiency impacts. In particular, I analyze taxes on land rents, bequests and aggregate physical capital.

1.4 Thesis objective and outline

Inequality has risen significantly over the last decades within many developed countries: This increase in inequality manifests itself in an increased wealth concentration in the top income percentile, a decreasing income share of labor (OECD, 2012) and a general increase in income inequality in most OECD countries (OECD, 2011). At the same time, investment in public capital is suboptimally low (Bom and Ligthart, 2014), and insufficiently regulated carbon emissions threaten millions of future lives by causing global warming (IPCC, 2014b). The last two problems are a consequence of mismanaged global common goods.

This thesis studies the equity and efficiency impacts of different types of regulations of common goods from a theoretical point of view. Specifically, I focus on the following question: *Can policies that regulate the use and the supply of common goods be designed such that they reduce inequality?*

The research presented in the subsequent chapters is separated into two parts. Each part corresponds to one common good: In Part I, I study the equity effects of environmental regulations in a model of households that differ in their earning abilities. I further discuss potentially beneficial interactions between public and climate policies. In Part II, I use different models of household heterogeneity in wealth to analyze the equity and efficiency effects of different ways of financing infrastructure.

Part I: The atmosphere

In **Chapter 2** I analyze different designs for carbon tax reforms in a small analytical model.[22] A carbon tax reform consists of a carbon tax combined with a revenue recycling mechanism. I explicitly account for the fact that households need to consume a minimum level of CO_2-intensive goods and that they are heterogeneous in their earning abilities. The main result from this study is that if carbon tax revenue is redistributed via uniform lump-sum transfers, a carbon tax reform reduces inequality. By contrast, if recycling occurs through linear income tax cuts, inequality is increased.

In **Chapter 3** I further develop the analytical model from Chapter 2 into an optimal taxation model.[23] Additionally, I account for endogenous prices,

[22]Chapter 2 is based on Klenert, D. and Mattauch, L., 2016. How to make a carbon tax reform progressive: The role of subsistence consumption. *Economics Letters* 138: 100-103, (http://dx.doi.org/10.1016/j.econlet.2015.11.019). A previous version is available as an MPRA Working Paper: Klenert, D., and Mattauch, L. 2015. How to make a carbon tax reform progressive: The role of subsistence consumption. MPRA Working Paper, 65919.

[23]Chapter 3 is based on Klenert, D., Schwerhoff, G., Edenhofer, O., and Mattauch, L., 2016. Environmental Taxation, Inequality and Engel's Law: The Double Dividend of Redistribution. *Environmental and Resource Economics*. The final publication is available at Springer via http://dx.doi.org/10.1007/s10640-016-0070-y.

more general functional forms and non-linear tax cuts – due to the resulting complex structure of the model it can only be solved numerically. This chapter goes beyond earlier analytical studies of optimal environmental taxation in a Mirrlees (1971) type model in at least four aspects: The numerical solution allows for (i) determining more informative optimal tax rates instead of optimal tax rules, (ii) quantifying the distributional impacts of an optimal environmental tax reform, (iii) taking price effects into account and, (iv), a detailed analysis of the case of non-linear income taxes combined with linear environmental taxes. I obtain three main results: First, an optimal tax system can always adjust to regressive carbon taxes with only minor changes in inequality by adjusting the income tax rates. Second, if the government can also use uniform lump-sum transfers to redistribute additional carbon revenues, there is scope for reducing inequality. Third, if the pre-existing tax system is calibrated to stylized facts of the U.S. economy, there is a large scope for an inequality-reducing carbon tax reform, if the revenue is redistributed either via non-linear income tax cuts or uniform lump-sum transfers. I call this effect the *double dividend of redistribution*.

Chapter 4 provides an overview of different beneficial interactions between fiscal and climate policies.[24] Effects reviewed include interactions on the revenue-raising side, for example the potential of climate policy to reduce tax competition or induce beneficial shifts in investors' portfolios, and on the spending side, such as increasing the level of public spending by means of carbon tax revenues. Finally it is discussed to what extent intragenerational equity depends on appropriate revenue recycling and if intergenerational Pareto-improvements are possible through intertemporal transfers. This chapter shows that there indeed might be scope for a significant reduction in the costs of climate policy if interactions with fiscal policy are taken into account.

Part II: Infrastructure

Chapter 5 analyzes the equity and efficiency effects of capital tax-financed public investment in infrastructure.[25] The structure of household heterogeneity in the model is based on key empirical insights about saving behavior. This chapter demonstrates, by means of a small analytical two-class model, that a capital tax can be both Pareto-improving and inequality-reducing, if the tax revenue is used for investment in productivity-enhancing infrastructure. Furthermore, it is proved that a variant of the Pasinetti (1962) Paradox holds

[24]Chapter 4 is based on Siegmeier, J., Mattauch, L., Franks, M., Klenert, D., Schultes, A., and Edenhofer, O., 2016. The fiscal benefits of climate policy: an overview. In preparation for submission to *CESifo Economic Studies*. A previous version is available as a FEEM Working Paper: Siegmeier, J., Mattauch, L., Franks, M., Klenert, D., Schultes, A., Edenhofer, O., 2015. A Public Finance Perspective on Climate Policy: Six Interactions That May Enhance Welfare. FEEM Nota di lavoro, 31.2015.

[25]Chapter 5 is based on Mattauch, L., Edenhofer, O., Klenert, D., and Bénard, S., 2016. Distributional Effects of Public Investment when Wealth and Classes are Back. *Metroeconomica*, 67(3), 603-629, (http://dx.doi.org/10.1111/meca.12117). A previous version is available as a CESifo Working Paper: Mattauch, L., Edenhofer, O., Klenert, D., Bénard, S., 2014. Public Investment When Capital is Back - Distributional Effects of Heterogeneous Saving Behavior. CESifo Working Paper No. 4714.

in this model.

In **Chapter 6**, the model from Chapter 5 is generalized in three aspects:[26] First, the labor supply is modeled endogenously in order to compare more financing options for infrastructure investment such as labor income and consumption taxation. Second, more general functional forms are used to analyze the effect of varied elasticities of substitution. Third, more channels through which infrastructure affects equity and efficiency are analyzed to make the model more realistic. The result from Chapter 5, that capital tax-financed infrastructure reduces inequality, is confirmed in a more general setting. However, consumption and labor income taxes are found to be more efficient than capital taxes (even though all three financing mechanism lead to a Pareto improvement, at least for low tax rates). Consumption tax financing is found to be neutral on the distribution while labor tax financing increases inequality. Some of these results, especially those concerning inequality in wealth and welfare, and the results for consumption tax financing, differ from the findings in earlier literature on the topic. This literature claims that inequality in wealth and welfare is always increased by infrastructure investment, independent of its financing, and that consumption tax financing leads to increased inequality in wealth, welfare and income.

Chapter 7 analyzes the output effects of policies that target wealth inequality directly.[27] Specifically, the claim that taxing capital has the potential to reduce wealth inequality is analyzed in a model of bequest heterogeneity. It is found that a tax on aggregate capital indeed reduces inequality. However, in accordance with the literature, such a tax has adverse effects on total output. By disaggregating wealth into land and physical capital, and by distinguishing life-cycle and bequest saving motives, the study demonstrates that taxing bequests and land rents also greatly reduces inequality, but without reducing total output: A combination of the two taxes can reduce inequality substantially while holding aggregate output constant. A land rent tax alone even enhances output due to a beneficial portfolio effect. In sum, high capital taxes for the purpose of reducing inequality are a policy recommendation which should be treated cautiously due to their adverse growth effects. If possible, capital taxes should be directed at wealth components which, when taxed, do not reduce capital formation too much, such as a bequest tax, or which increase investment in capital, such as land rent taxes.

[26] Chapter 6 is based on Klenert, D., Mattauch, L., Edenhofer, O. and Lessmann, K., 2016. Infrastructure and Inequality: Insights from Incorporating Key Economic Facts about Household Heterogeneity. *Macroeconomic Dynamics*. First view (http://dx.doi.org/10.1017/S1365100516000432). A preliminary version of the article has been published as a CESifo working paper: Klenert, D., Mattauch, L., Edenhofer, O., & Lessmann, K., 2014. Infrastructure and Inequality: Insights from Incorporating Key Economic Facts about Household Heterogeneity. CESifo Working Paper, 4972.

[27] Chapter 7 is based on Franks, M., Klenert, D., Schultes, A. Lessmann, K. and Edenhofer, O., 2016. Is capital back? The role of land ownership and saving behavior. In preparation for submission to *FinanzArchiv/Public Finance Analysis*.

Chapter 8 concludes this thesis. It summarizes and links the insights derived in the preceding chapters and discusses their implications for policy making. It further provides an outlook on possible future research.

References

Acemoglu, D., Robinson, J. A., 2014. The Rise and Decline of General Laws of Capitalism. NBER Working Paper Series 20766.

Agénor, P.-R., 2013. Public Capital, Growth and Welfare. Analytical Foundations for Public Policy. Princeton University Press.

Alesina, A., Rodrik, D., 1994. Distributive Politics and Economic Growth. The Quarterly Journal of Economics 109(2), 465–490.

Alvaredo, F., Atkinson, A. B., Piketty, T., Saez, E., 2013. The Top 1 Percent in International and Historical Perspective. Journal of Economic Perspectives 27(3), 3–20.

Arnott, R. J., Stiglitz, J. E., 1979. Aggregate land rents, expenditure on public goods, and optimal city size. Quarterly Journal of Economics 93(4), 471–500.

Arrow, K. J., Cropper, M. L., Gollier, C., Groom, B., Heal, G. M., Newell, R. G., Nordhaus, W. D., Pindyck, R. S., Pizer, W. A., Portney, P. R., Sterner, T., Tol, R. S. J., Weitzman, M. L., 2013. How Should Benefits and Costs Be Discounted in an Intergenerational Context? University of Sussex: Business, Management and Economics Department Working Paper Series 56.

Aschauer, D. A., 1989. Is public expenditure productive? Journal of Monetary Economics 23(2), 177–200.

Atkinson, A., Stiglitz, J., 1976. The design of tax structure: Direct versus indirect taxation. Journal of Public Economics 6(1–2), 55–75.

Atkinson, A. B., 2015. Inequality: What Can Be Done? Harvard University Press.

Atkinson, A. B., Piketty, T., Saez, E., 2011. Top Incomes in the Long Run of History. Journal of Economic Literature 49(1), 3–71.

Attanasio, O. P., 1994. Personal Saving in the United States. In: Poterba, J. M. (Ed.), International Comparisons of Household Saving, January, pp. 57–124, University of Chicago Press.

Azar, J., Raina, S., Schmalz, M. C., 2016. Ultimate Ownership and Bank Competition. `http://papers.ssrn.com/abstract=2710252`, Working Paper.

Babiker, M. H., Eckaus, R. S., 2007. Unemployment effects of climate policy. Environmental Science & Policy 10, 600–609.

Barrett, S., 1999. A theory of full international cooperation. Journal of Theoretical Politics 11(4), 519–541.

Barro, R. J., 1990. Government spending in a simple model of endogenous growth. Journal of Political Economy 98(5), 103–125.

Berg, A., Ostry, J. D., Zettelmeyer, J., 2012. What makes growth sustained? Journal of Development Economics 98(2), 149–166.

Berg, A. G., Ostry, J. D., 2011. Inequality and Unsustainable Growth: Two Sides of the Same Coin ? IMF Staff Discussion Note .

Bom, P. R., Ligthart, J. E., 2014. What Have We Learned From Three Decades of Research on the Productivity of Public Capital? Journal of Economic Surveys 28(5), 889–916.

Bovenberg, A. L., Heijdra, B. J., 1998. Environmental tax policy and intergenerational distribution. Journal of Public Economics 67(1), 1–24.

Browning, M., Lusardi, A., 1996. Household Saving: Micro Theories and Micro Facts. Journal of Economic literature 34(4), 1797–1855.

Burkhauser, R. V. ., De Neve, J.-E., Powdthavee, N., 2015. Top Incomes and Human Well-Being Around the World. Said Business School Research Papers 2015-25(December).

Bush, J. E., 2015. Backgrounder: Jeb bush's tax reform plan: The reform and growth act of 2017. `https://jeb2016.com/backgrounder-jeb-bushs-tax-reform-plan/?lang=en`, retrieved January 7, 2016.

Cagetti, M., De Nardi, M., 2008. Wealth inequality: Data and models. Macroeconomic Dynamics 12(S2), 285–313.

Calderón, C., Chong, A., 2004. Volume and quality of infrastructure and the distribution of income: an empirical investigation. Review of Income and Wealth 50(1), 87–106.

Calderón, C., Moral-Benito, E., Servén, L., 2015. Is Infrastructure Capital Productive? A Dynamic Heterogeneous Approach. Journal of Applied Econometrics 30, 177–198.

Calderón, C., Servén, L., 2014a. Infrastructure and inequality. In: Durlauf, S. N., Blume, L. E. (Eds.), The New Palgrave Dictionary of Economics. Online Edition., Palgrave Macmillan, Basingstoke, accessed: 1 December 2014.

Calderón, C., Servén, L., 2014b. Infrastructure and growth. In: Durlauf, S. N., Blume, L. E. (Eds.), The New Palgrave Dictionary of Economics. Online Edition., Palgrave Macmillan, Basingstoke, accessed: 1 December 2014.

Carraro, C., Siniscalco, D., 1993. Strategies for the international protection of the environment. Journal of Public Economics 52, 309–328.

Carroll, C. D., 2000. Why Do the Rich Save So Much? In: Joel B. Slemrod (Ed.), Does Atlas Shrug? The Economic Consequences of Taxing the Rich, pp. 465–84, Harvard University Press.

Cass, D., 1965. Optimum growth in an aggregative model of capital accumulation. The Review of Economic Studies 32(3), 233–240.

CCL, 2016. Citizens' Climate Lobby | Creating the political will for a livable world! `http://www.citizensclimatelobby.org/`, retrieved 2016-01-10.

Cederman, L.-E., Weidmann, N. B., Gleditsch, K. S., 2011. Horizontal inequalities and ethnonationalist civil war: A global comparison. American Political Science Review 105(3), 478–495.

Chamley, C., 1986. Optimal Taxation of Capital Income in General Equilibrium with Infinite Lives. Econometrica 54(3), 607–622.

Chatterjee, S., Turnovsky, S. J., 2012. Infrastructure and inequality. European Economic Review 56, 1730–1745.

Chiroleu-Assouline, M., Fodha, M., 2011. Environmental Tax and the Distribution of Income among Heterogeneous Workers. Annals of Economics and Statistics 103/104, 71–92.

Chiroleu-Assouline, M., Fodha, M., 2014. From regressive pollution taxes to progressive environmental tax reforms. European Economic Review 69, 126–142.

Church, J. a., Clark, P. U., Gregory, J. M., Jevrejeva, S., Levermann, A., Merrifield, M. a., Milne, G. a., Nerem, R. S., Nunn, P. D., Payne, A. J., Pfeffer, W. T., Stammer, D., Unnikrishnan, A. S., 2013. Sea-Level Rise by 2100. Science 342(December), 1445.

Combet, E., Ghersi, F., Hourcade, J.-C., Théry, D., 2010. Carbon Tax and Equity The importance of Policy Design. In: Dias Soares, C., Milne, J., Ashiabor, H., Deketelaere, K. (Eds.), Critical Issues in Environmental Taxation vol. VIII, pp. 277–295.

Corak, M., 2013. Income inequality, equality of opportunity, and intergenerational mobility. Journal of Economic Perspectives 27(3), 79–102.

Cremer, H., Gahvari, F., Ladoux, N., 1998. Externalities and optimal taxation. Journal of Public Economics 70(3), 343–364.

Diaz-Gimenez, J., Glover, A., Rios-Rull, J.-V., 2011. Facts on the Distributions of Earnings, Income, and Wealth in the United States: 2007 Update. Federal Reserve Bank of Minneapolis Quarterly Review 34(1).

Dwyer, T., 2014. Taxation: The lost history. American Journal of Economics and Sociology 73(4), 664–988.

Dynan, K. E., Skinner, J., Zeldes, S. P., 2004. Do the Rich Save More? Journal of Political Economy 112(2), 397–444.

Edenhofer, O., Flachsland, C., Jakob, M., Lessmann, K., 2012. The Atmosphere as a Global Commons – Challenges for International Cooperation and Governance. In: Semmler, W., Bernard, L. (Eds.), The Oxford Handbook of the Macroeconomics of Global Warming, August.

Edenhofer, O., Jakob, M., Creutzig, F., Flachsland, C., Fuss, S., Kowarsch, M., Lessmann, K., Mattauch, L., Siegmeier, J., Steckel, J. C., 2015a. Closing the emission price gap. Global Environmental Change 31, 132–143.

Edenhofer, O., Mattauch, L., Siegmeier, J., 2015b. Hypergeorgism: When rent taxation is socially optimal. FinanzArchiv: Public Finance Analysis 71(4), 474–505.

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Kadner, S., Minx, J., Brunner, S., Agrawala, S., Baiocchi, G., Bashmakov, I., Blanco, G., Broome, J., Bruckner, T., Bustamante, M., Clarke, L., Conte Grand, M., Creutzig, F., Cruz-Núñez, X., Dhakal, S., Dubash, N., Eickemeier, P., Farahani, E., Fischedick, M., Fleurbaey, M., Gerlagh, R., Gómez-Echeverri, L., Gupta, S., Harnisch, J., Jiang, K., Jotzo, F., Kartha, S., Klasen, S., Kolstad, C., Krey, V., Kunreuther, H., Lucon, O., Masera, O., Mulugetta, Y., Norgaard, R. B., Patt, A., Ravindranath, N., Riahi, K., Roy, J., Sagar, A., Schaeffer, R., Schlömer, K., S. Seto, Seyboth, K., Sims, R., Smith, P., Somanathan, E., Stavins, R., von Stechow, C., Sterner, T., Sugiyama, T., Suh, S., Ürge Vorsatz, D., Urama, K., Venables, A., Victor, D., Weber, E., Zhou, D., Zou, J., Zwickel, T., 2014. Technical summary. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., Minx, J. (Eds.), Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

EEA, 2015. Air quality in Europe – 2015 report. European Environment Agency.

Ekins, P., 1999. European environmental taxes and charges: recent experience, issues and trends. Ecological Economics 31(1), 39–62.

Estache, A., Fay, M., 2007. Current Debates on Infrastructure Policy. The World Bank Policy Research Working Paper 4410(November).

Feldstein, M. S., 1977. The surprising incidence of a tax on pure rent: A new answer to an old question. Journal of Political Economy 85(2), 349–360.

Flues, F., Thomas, A., 2015. The Distributional Effects of Energy Taxes: Preliminary Report. OECD Taxation Working Papers .

Foley, D. K., 2008. The economic fundamentals of global warming. In: Harris, J. M., Goodwin, N. R. (Eds.), Twenty-First Century Macroeconomics: Responding to the Climate Challenge, Edward Elgar Publishing, Northampton.

Frydman, C., Saks, R. E., 2010. Executive Compensation: A New View from a Long-Term Perspective, 1936-2005. Review of Financial Studies 23(5), 2099–2138.

Fullerton, D., 2011. Six distributional effects of environmental policy. Risk analysis 31(6), 923–9.

Fullerton, D., Monti, H., 2013. Can pollution tax rebates protect low-wage earners? Journal of Environmental Economics and Management 66(3), 539–553.

Gale, W. G., Scholz, J. K., 1994. Intergenerational Transfers and the Accumulation of Wealth. The Journal of Economic Perspectives 8(4), 145–160.

George, H., 1879/2006. Progress and Poverty. An inquiry into the cause of industrial depressions and of increase of want with increase of wealth. The Remedy. Elibron Classics, reprint of the 1894 edition.

Glomm, G., Ravikumar, B., 1994. Growth-Inequality Trade-Offs in a Model with Public Sector R&D. Canadian Journal of Economics/Revue canadienne d'Economique 27(2), 484–493.

Goldsmith, H., 2014. The Long-Run Evolution of Infrastructure Services. CESifo Working Paper 5073.

Grainger, C. A., Kolstad, C. D., 2010. Who Pays a Price on Carbon? Environmental and Resource Economics 46(3), 359–376.

Gramlich, E. M., 1994. Infrastructure investment: A review essay. Journal of Economic Literature 32(3), 1176–1196.

Green, L., Myerson, J., Lichtman, D., Rosen, S., Fry, A., 1996. Temporal Discounting in Choice Between Delayed Rewards : The Role of Age and Income. Psychology and Aging I, 79–84.

Hardin, G., 1968. The tragedy of the commons. Science 162(June), 1243–1248.

Heijdra, B. J., Bovenberg, a. L., 2002. Environmental Abatement and Intergenerational Distribution. Environmental and Resource Economics 23(1), 45–84.

Homburg, S., 2015. Critical remarks on Piketty's Capital in the Twenty-first Century. Applied Economics 47(14), 1401–1406.

IPCC, 2013. 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC, 2014a. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Field, C.B. and Barros, V.R. and Dokken, D.J. and Mach, K.J. and Mastrandrea, M.D. and Bilir, T. E. and Chatterjee, M. and Ebi, K.L. and Estrada, Y.O. and Genova, R.C. and Girma, B. and Kissel, E.S. and Levy, A. N. and MacCracken, S. and Mastrandrea, P.R. and White, L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2014b. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Jacobs, B., De Mooij, R., 2015. Pigou meets Mirrlees: on the irrelevance of tax distortions for the second-best Pigouvian tax. Journal of Environmental Economics and Management 71, 90–108.

Jakob, M., Edenhofer, O., 2014. Green growth, degrowth, and the commons. Oxford Review of Economic Policy 30(3), 447–468.

Jakob, M., Hilaire, J., 2015. Unburnable fossil-fuel reserves. Nature 517(January), 150–152.

Judd, K. L., 1985. Redistributive taxation in a simple perfect foresight model. Journal of Public Economics 28(1), 59–83.

Kaldor, N., 1955. Alternative theories of distribution. The Review of Economic Studies 23(2), 83–100.

Kamps, C., 2006. New estimates of government net capital stocks for 22 OECD countries 1960-2001. IMF Staff Papers 53(1), 120–150.

Kaplow, L., 2012. Optimal control of externalities in the presence of income taxation. International Economic Review 53(2), 487–509.

Karp, L., Rezai, A., 2014. The political economy of environmental policy with overlapping generations. International Economic Review 55(3), 711–733.

Kaul, I., Grunberg, I., Stern, M., 1999. Global public goods: international cooperation in the 21st century. Oxford University Press.

Koopmans, T. C., 1965. On the concept of optimal economic growth. In: The Econometric Approach to Development Planning, Rand-McNally.

Kopczuk, W., 2013. Taxation of Intergenerational Transfers and Wealth. In: Auerbach, A. J., Chetty, R., Feldstein, M., Saez, E. (Eds.), Handbook of Public Economics, volume 5, Newnes.

Kornek, U., 2015. Designing International Climate Agreements: An Economic Analysis of Free-Riding Incentives. PhD thesis.

Krusell, P., Smith, A. A., 1998. Income and Wealth Heterogeneity in the Macroeconomy. Journal of Political Economy 106(5), 867–896.

Kumhof, M., Rancière, R., Winant, P., 2015. Inequality , Leverage , and Crises. American Economic Review 105(3), 1217–1245.

Lawrance, E. C., 1991. Poverty and the Rate of Time Preference: Evidence from Panel Data. Journal of Political Economy 99(1), 54–77.

Levinson, A., O'Brien, J., 2015. Environmental Engel Curves. NBER Working Paper Series 20914.

Liebig, S., 2012. Richard Wilkinson and Kate Pickett (2009): The spirit level. Why more equal societies almost always do better. Allen Lane, London. [Review]. Social Justice Research 25(1), 102–107.

Lund, C., Breen, A., Flisher, a. J., Kakuma, R., Corrigall, J., Joska, J. a., Swartz, L., Patel, V., 2010. Poverty and common mental disorders in low and middle income countries: A systematic review. Social Science & Medicine 71, 517–528.

Maddison, A., 2007. Contours of the world economy 1-2030 AD: Essays in macro-economic history. Oxford University Press.

Marrero, G. A., Rodríguez, J. G., 2013. Inequality of opportunity and growth. Journal of Development Economics 104, 107–122.

Mattauch, L., 2015. Rent and Redistribution. The welfare implications of financing low-carbon public investment. PhD thesis.

Mattauch, L., Siegmeier, J., Edenhofer, O., Creutzig, F., 2013. Financing public capital through land rent taxation: A macroeconomic Henry George Theorem. CESifo Working Paper 4280, 1–20.

Michl, T. R., 2009. Capitalists, workers, and fiscal policy: a classical model of growth and distribution. Harvard University Press, Cambridge, MA.

Michl, T. R., Foley, D. K., 2004. Social security in a classical growth model. Cambridge Journal of Economics 28(1), 1–20.

Milanovic, B., 2013. Global Income Inequality in Numbers: In History and Now. Global Policy 4(2), 198–208.

Milanovic, B., 2014a. A Review of Thomas Piketty's Capital in the Twenty-First Century. Journal of Economic Literature 52(2), 519–534.

Milanovic, B., 2014b. My take on the Acemoglu-Robinson critique of Piketty. `http://glineq.blogspot.de/2014/08/my-take-on-acemoglu-robinson-critique.html`, Blog post from August 23, 2014.

Mirrlees, J., 1971. An Exploration in the Theory of Optimum Income Taxation. The Review of Economic Studies 38(2), 175–208.

Mishel, L., Gould, E., Bivens, J., 2015. Wage stagnation in nine charts. Economic Policy Institute .

Noble, H., 2009. Comments on the Spirit Level Controversy. Radical Statistics 104, 49–60.

Nordhaus, W. D., 1994. Managing the global commons: the economics of climate change. MIT Press.

Nordhaus, W. D., 2007. A Review of the Stern Review on the Economics of Climate Change. Journal of Economic Literature XLV, 686–702.

Norton, M. I., Ariely, D., 2011. Building a Better America - One Wealth Quintile at a Time. Perspectives on Psychological Science 6(1), 9–12.

OECD, 2006. Infrastructure to 2030. Telecom, Land Transport, Water and Electricity, volume 1.

OECD, 2007. Infrastructure to 2030. Mapping Policy for Electricity, Water and Transport, volume 2.

OECD, 2011. Divided we stand: Why inequality keeps rising. OECD Publishing pp. 21–45.

OECD, 2012. Chapter 3: Labour Losing to Capital: What Explains the Declining Labour Share? In: OECD (Ed.), Employment Outlook, pp. 109–161.

OECD, 2015a. Economic Policy Reforms 2015: Going for Growth, volume 21.

OECD, 2015b. In it together: Why less inequality benefits all. Technical report.

Okun, A. M., 1975. Equality and efficiency: The big tradeoff. Brookings Institution Press.

Ostby, G., 2008. Horizontal inequalities, the political environment and civil conflict: Evidence from 55 developing countries. In: Stewart, F. (Ed.), Horizontal Inequalities and Conflict: Understanding Group Violence in Multiethnic Societies, pp. 136–157, Palgrave Macmillan.

Ostby, G., Strand, H., 2013. Horizontal inequalities and internal conflict: The impact of regime type and political leadership regulation. In: Kalu, K., Uzodike, U. O., Kraybill, D., Moolakkatu, J. (Eds.), Territoriality, Citizenship, and Peacebuilding: Perspectives on Challenges to Peace in Africa, pp. 139–188, Adonis & Abbey.

Pachauri, S., 2004. An analysis of cross-sectional variations in total household energy requirements in India using micro survey data. Energy Policy 32, 1723–1735.

Pasinetti, L. L., 1962. Rate of profit and income distribution in relation to the rate of economic growth. The Review of Economic Studies 29(4), 267–279.

Perman, R., 2003. Natural Resource and Environmental Economics. Pearson Education Limited 2003.

Piketty, T., 2014. Capital in the Twenty-first Century. Harvard University Press.

Piketty, T., Saez, E., 2012. A Theory of Optimal Capital Taxation. NBER Working Paper Series 17989.

Piketty, T., Saez, E., 2013. A Theory of Optimal Inheritance Taxation. Econometrica 81(5), 1851–1886.

Piketty, T., Saez, E., Stantcheva, S., 2014. Optimal taxation of top labor incomes: A tale of three elasticities. American Economic Journal: Economic Policy 6(1), 230–271.

Piketty, T., Zucman, G., 2014. Capital is back: Wealth-Income Rations in Rich Countries 1700-2010. Quarterly Journal of Economics 129(3), 1255–1310.

Quadrini, V., 1997. Understanding the U. S. Distribution of Wealth. Federal Reserve Bank of Minneapolis Quarterly Review 21(2), 22–36.

Ramsey, F. P., 1928. A mathematical theory of saving. Economic Journal 38(152), 543–559.

Rausch, S., Metcalf, G. E., Reilly, J. M., 2011. Distributional impacts of carbon pricing: A general equilibrium approach with micro-data for households. Energy Economics 33(Supplement 1), 20 – 33.

Rausch, S., Reilly, J. M., Metcalf, G. E., Paltsev, S., 2010. Distributional Implications of Alternative U . S . Distributional Implications of Alternative U . S . Greenhouse Gas Control Measures. The B.E. Journal of Economic Analysis & Policy 10(2).

Rezai, A., Foley, D. K., Taylor, L., 2012. Global warming and economic externalities. Economic Theory 49(2), 329–351.

Roemer, J. E., 1993. A pragmatic theory of responsibility for the egalitarian planner. Philosophy & Public Affairs 22(2), 146–166.

Rognlie, M., 2014. A note on Piketty and diminishing returns to capital. http://economics.mit.edu/files/11191, working paper version from June 15, 2014.

Romp, W., Haan, J. D., 2007. Public capital and economic growth: A critical survey. Perspektiven der Wirtschaftspolitik 8(Special Issue), 6–52.

Saez, E., Zucman, G., 2015. Wealth Inequality in the United States since 1913. Working Paper August.

Schultes, A., Edenhofer, O., Leimbach, M., 2015. Biased Climate Damages and Intergenerational Impacts. Mimeo .

Schwerhoff, G., Franks, M., 2016. Optimal Environmental Taxation with Capital Mobility. Unpublished Working Paper .

Shah, A., Larsen, B., 1992. Carbon Taxes , the Greenhouse Effect , and Developing Countries. World Development Report Policy Papers WPS 957.

Siegmeier, J., Mattauch, L., Edenhofer, O., 2015. Climate Policy Enhances Efficiency: A Macroeconomic Portfolio Effect. CESifo Working Paper 5161.

Stern, N., Peters, S., Bakshi, V., Bowen, A., Cameron, C., Catovsky, S., Crane, D., Cruickshank, S., Dietz, S., Edmonson, N., et al, 2006. Stern Review: The Economics of Climate Change. AHM Treasury, London.

Sterner, T., 2011. Fuel Taxes and the Poor: The Distributional Effects of Gasoline Taxation and Their Implications for Climate Policy. Johns Hopkins University Press.

Stiglitz, J., 2012. The price of inequality: How today's divided society endangers our future. W.W. Norton, New York, NY.

Stiglitz, J. E., 2015a. New Theoretical Perspectives on the Distribution of Income and Wealth among Individuals: Part I. The Wealth Residual. NBER Working Paper Series May(21189).

Stiglitz, J. E., 2015b. New Theoretical Perspectives on the Distribution of Income and Wealth among Individuals Part II: Equilibrium Wealth Distributions. NBER Working Paper Series May(21190).

Stiglitz, J. E., 2015c. New Theoretical Perspectives on the Distribution of Income and Wealth Among Individuals Part III: Life Cycle Savings Vs Inherited Savings. NBER Working Paper Series May(21191).

Stiglitz, J. E., 2015d. New Theoretical Perspectives on the Distribution of Income and Wealth Among Indviduals Part IV: Land and Credit. NBER Working Paper Series May(21192).

Stiglitz, J. E., 2015e. The Origins of Inequality, and Policies to Contain It. National Tax Journal 68(2), 425–448.

Stocker, T., Qin, D., Plattner, G.-K., Alexander, L., Allen, S., Bindoff, N., BrÃ©on, F.-M., Church, J., Cubasch, U., Emori, S., Forster, P., Friedlingstein, P., Gillett, N., Gregory, J., Hartmann, D., Jansen, E., Kirtman, B., Knutti, R., Krishna Kumar, K., Lemke, P., Marotzke, J., Masson-Delmotte, V., Meehl, G., Mokhov, I., Piao, S., Ramaswamy, V., Randall, D., Rhein, M., Rojas, M., Sabine, C., Shindell, D., Talley, L., Vaughan, D., Xie, S.-P., 2013. Technical summary. In: Stocker, T., Qin, D., Plattner, G.-K., Tignor, M., Allen, S., Boschung, J., Nauels, A., Xia, Y., V., B., Midgley, P. (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

The Guardian, 2010. James Hansen rails against cap-and-trade plan in open letter. The Guardian. `http://www.theguardian.com/environment/2010/jan/12/james-hansen-carbon-emissions`, retrieved 2016-01-10.

Tietenberg, T. H., 1990. Economic Instruments for Environmental Regulation. Oxford Review of Economic Policy 6(1), 17–33.

UNFCCC, 2015. Adoption of the paris agreement. In: FCCC/CP/2015/L.9/Rev.1 (Ed.), United Nations Office at Geneva | Geneva (Switzerland) | 12/12/2015, `http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf`, retrieved 2016-01-10.

Uzawa, H., 2005. Economic Analysis of Social Common Capital. Cambridge University Press.

WEF, 2013. Strategic Infrastructure. Steps to Prepare and Accelerate Public-Private Partnerships. World Economic Forum (May).

Wier, M., Lenzen, M., Munksgaard, J., Smed, M., 2001. Effects of Household Consumption Patterns on CO_2 Requirements. Economic Systems Research 13(3), 259–274.

Wilkinson, R., Pickett, K., 2009. The Spirit Level: Why Equality is Better for Everyone. Penguin.

Wolff, E. N., 1998. Recent Trends in the Size Distribution of Household Wealth. Journal of Economic Perspectives 12(3), 131–150.

Wolff, E. N., 2010. Recent Trends in Household Wealth in the United States: Rising Debt and the Middle-Class Squeeze - an Update to 2007. The Levy Economics Institute Working Paper Collection .

Part I

The atmosphere as a common good

Chapter 2

How to make a carbon tax reform progressive: The role of subsistence consumption[1]

David Klenert
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How to make a carbon tax reform progressive: The role of subsistence consumption

David Klenert*, Linus Mattauch†

Abstract

This letter analyzes the distributional effects of a carbon tax reform when households must consume carbon-intensive goods above a subsistence level. The reform is progressive if revenues are recycled as uniform lump-sum transfers, in other cases it is regressive.

JEL classification: D30, D60, E62, H22, H23

Keywords: Carbon tax reform, distribution, revenue recycling, inequality, non-homothetic preferences

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1 Introduction

Mitigating climate change requires substantial reductions in carbon emissions, which can be achieved most cost-effectively by carbon pricing (Tietenberg, 1990). An important obstacle to introducing carbon pricing are distributional concerns: Pricing emissions in developed countries is often believed to harm the poorest part of the population due to the higher share of their income these households spend on carbon-intensive goods (Grainger and Kolstad, 2010; Fullerton, 2011; Combet et al., 2010).

Grainger and Kolstad (2010) show, for the case of the US, that there is a subsistence level for most carbon-intensive goods and that a price increase in these goods is the main driver behind the regressivity of carbon taxes. This mechanism, has received scarce attention in the theoretical literature on the distributional implications of carbon tax reforms.

Analyzing the distributional effects of a carbon tax reform while accounting for a subsistence level of carbon-intensive goods is the purpose of the present note. We use a stylized analytical model that features two consumption goods, one of which is assumed to be carbon-intensive. Households differ only in their productivity and must consume a minimal amount of the carbon-intensive good to survive. We are only concerned with the short-term distributional effects of a carbon tax reform, i.e. how setting a price on carbon impacts inequality[1], which we believe to be decisive for political decision making.

We find three main results. First, when the tax revenue is returned to the households via linear income tax cuts, or in proportion to their productivity, the overall effect of the tax reform is regressive. Second, for the case of uniform lump-sum recycling, the overall effect of the tax reform is progressive. Finally, we show that when setting the subsistence level of carbon-intensive consumption to zero, regressive policies appear to be distribution-neutral.

Previous literature either relies on large numerical models (Rausch et al., 2010, 2011) or on rather specific modeling assumptions (Fullerton and Monti, 2013; Chiroleu-Assouline and Fodha, 2014).[2] In fact, there seems to be some disagreement in the theoretical literature on the extent to which the regressivity of a carbon tax can be reduced by the recycling of its revenues: Fullerton and Monti (2013) show that in a model with household heterogeneity in skills, "returning all of the revenue to low-skilled workers is still not enough to offset higher product prices." (p. 539) On the other hand, Chiroleu-Assouline and Fodha (2014) demonstrate that an environmental tax can always be designed to be Pareto-improving if the revenue is used for a progressive reform of the wage tax. They use a model in which pollution is a by-product of capital and hence interpret a capital tax as an environmental tax. Households differ in skill level and age. Both studies mention a subsistence level of polluting consumption as at least partially responsible for the regressivity of a carbon tax, but refrain from modeling it by means of non-homothetic preferences.

A large body of literature confirms that low income households spend a larger percentage of their income on carbon-intensive goods than high income households, notably on heating, electricity and food (see e.g. Grainger and

[1]This permits us to abstract from major factors usually discussed in the context of climate policy, such as environmental damages and structural change.

[2]A parallel strand of literature studies the interplay of carbon and income taxes in optimal taxation frameworks (Cremer et al., 1998; Jacobs and De Mooij, 2015; Klenert et al., 2015). Optimal carbon tax reforms under equity constraints are analyzed by Kaplow (2012).

Kolstad 2010; Flues and Thomas 2015 and Wier et al. 2001).[3] In the following we analyze the distributional impacts of a carbon tax reform when this mechanism is modeled explicitly.

2 The model

We use a two-sector model in which N households are distinguished by their productivity. Households need to consume a minimum amount of the polluting good. Since we only consider the short term (i.e. structural change is negligible), we use a static model. Furthermore we assume that commodity prices are fixed. Sources-side effects, which are likely to be progressive (Dissou and Siddiqui, 2014), are hence ignored and all the tax burden is assumed to rest on the consumers.[4]

Households: The households are distinguished only by their productivity ϕ_i, $i = 1 \dots N$. Each household is endowed with one unit of a production factor. A share l_i of the production factor is used at home and can be interpreted as leisure. For the remaining share $(1 - l_i)$, the household receives a rental rate w, so the households' incomes I_i are given by

$$I_i = \phi_i w(1 - l_i)(1 - \tau_w^0 + \tau_w). \tag{1}$$

Here τ_w^0 denotes the income tax before the carbon tax reform and τ_w is a potential (linear) income tax reduction financed by carbon tax revenues. We normalize the household productivities so that $\sum_{i=1}^N \phi_i = 1$.

Households derive utility from the consumption of clean goods C_i, polluting goods D_i and leisure l_i. They have identical non-homothetic preferences (due to the minimum-consumption requirement D_0 for the polluting commodity) and maximize utility, given by

$$U(C_i, D_i, l_i) = C_i^\alpha (D_i - D_0)^\beta l_i^\gamma, \tag{2}$$

with α, β, $\gamma > 0$. We assume that $\alpha + \beta + \gamma = 1$ to obtain more tractable formulas, but our findings also hold for $\alpha + \beta + \gamma \neq 1$. The utility function is not defined for $D_i < D_0$. The budget equation is given by

$$C_i \cdot p_C + D_i \cdot p_D \cdot (1 + \tau) = I_i + L_i, \tag{3}$$

with τ denoting a tax on the polluting commodity and L_i a lump-sum transfer. We assume constant commodity prices.

Maximizing utility (2) subject to the budget constraint (3) yields the first-order conditions of the households, which can be transformed to obtain explicit expressions for C_i, D_i and l_i:

$$C_i = \frac{\alpha}{p_C} \left(\phi_i w(1 - \tau_w^0 + \tau_w) + L_i - D_0 p_D (1 + \tau) \right), \tag{4}$$

$$D_i = \frac{\beta}{p_D(1 + \tau)} \left(\phi_i w(1 - \tau_w^0 + \tau_w) + L_i - D_0 p_D (1 + \tau) \right) + D_0, \tag{5}$$

[3] This might not be the case for developing countries, see Sterner (2011).

[4] For a study that also includes sources-side effects, see our more extensive numerical analysis (Klenert et al., 2015). However, accounting for potentially progressive effects of endogenous prices below would likely make our result from Proposition 2 stronger, while the effect on the result from Proposition 1 is unclear.

$$l_i = \frac{\gamma}{\phi_i w(1-\tau_w^0+\tau_w)} \left(\phi_i w(1-\tau_w^0+\tau_w) + L_i - D_0 p_D (1+\tau)\right). \tag{6}$$

Government: The (non-optimizing) government has a fixed spending requirement G, which is financed by the (pre-existing) income tax τ_w^0. Additional revenue can either be returned to the households via lump-sum transfers L_i or via reductions in the income tax τ_w. The government's budget constraint thus reads:

$$G + \sum_{i=1}^{N} L_i + \sum_{i=1}^{N} \phi_i w(1-l_i)\tau_w = \tau \cdot D \cdot p_D + \sum_{i=1}^{N} \phi_i w(1-l_i)\tau_w^0. \tag{7}$$

3 Results

We analyze the distributional implications of three carbon tax reforms. Each reform consists of a carbon tax combined with a revenue recycling-scheme. We consider recycling through (i) lump-sum transfers in proportion to household productivities, (ii) linear income tax reductions and (iii) uniform lump-sum transfers.

We show in Proposition 1 that in the first and second case, inequality increases. In the third case, inequality is reduced (Proposition 2). Finally, we demonstrate in Proposition 3 that recycling the revenues as in the first and second case is distribution-neutral when the subsistence level of polluting consumption equals zero.

We consider the utility ratio of two households as a measure of the distributional impacts of the carbon tax reform, since analyzing the income ratios would not capture the necessity of consuming at least an amount D_0 of the polluting commodity. We verified numerically that our findings also hold when the Gini coefficient in utility is used as a measure of inequality.[5]

The ratio of the indirect utilities of households i and j is:

$$\begin{aligned}\frac{U_i}{U_j} &= \frac{C_i^\alpha (D_i - D_0)^\beta l_i^\gamma}{C_j^\alpha (D_j - D_0)^\beta l_j^\gamma} \\ &= \left(\frac{\phi_j}{\phi_i}\right)^\gamma \left(\frac{(\phi_i w(1-\tau_w^0+\tau_w) + L_i - D_0 p_D(1+\tau))}{(\phi_j w(1-\tau_w^0+\tau_w) + L_j - D_0 p_D(1+\tau))}\right)\end{aligned}$$

We denote by $\left(U_i/U_j\right)^{\text{BT}}$ the ratio of utilities before taxes, $\left(U_i/U_j\right)^{\text{AT-P}}$ the case of a tax with the revenues recycled in proportion to each household's productivity ϕ_i, $\left(U_i/U_j\right)^{\text{AT-T}}$ the case of a tax with the revenues recycled via linear income tax reductions and $\left(U_i/U_j\right)^{\text{AT-U}}$ the ratio of utilities after taxes with uniform lump-sum recycling of the revenues:

$$\left(\frac{U_i}{U_j}\right)^{\text{BT}} = \left(\frac{\phi_j}{\phi_i}\right)^\gamma \left(\frac{\phi_i w(1-\tau_w^0) - D_0 p_D}{\phi_j w(1-\tau_w^0) - D_0 p_D}\right), \tag{8}$$

$$\left(\frac{U_i}{U_j}\right)^{\text{AT-P}} = \left(\frac{\phi_j}{\phi_i}\right)^\gamma \left(\frac{\phi_i (w(1-\tau_w^0) + \tau p_D D) - D_0 p_D(1+\tau)}{\phi_j (w(1-\tau_w^0) + \tau p_D D) - D_0 p_D(1+\tau)}\right), \tag{9}$$

[5]These results are available upon request.

$$\left(\frac{U_i}{U_j}\right)^{\text{AT-T}} = \left(\frac{\phi_j}{\phi_i}\right)^{\gamma}\left(\frac{\phi_i w(1-\tau_w^0+\tau_w) - D_0 p_D(1+\tau)}{\phi_j w(1-\tau_w^0+\tau_w) - D_0 p_D(1+\tau)}\right), \tag{10}$$

$$\left(\frac{U_i}{U_j}\right)^{\text{AT-U}} = \left(\frac{\phi_j}{\phi_i}\right)^{\gamma}\left(\frac{\phi_i w(1-\tau_w^0) + \tau D p_D \frac{1}{N} - D_0 p_D(1+\tau)}{\phi_j w(1-\tau_w^0) + \tau D p_D \frac{1}{N} - D_0 p_D(1+\tau)}\right). \tag{11}$$

Proposition 1. *The incidence of a tax on the polluting good is* regressive *if the revenues are recycled*

(a) in proportion to each household's productivity ϕ_i (i.e. $L_i = \phi_i \tau p_D D$ and $\tau_w = 0$).

(b) via linear income tax cuts τ_w (i.e. $\tau_w w \sum_{i=1}^{N} \phi_i(1-l_i) = \tau p_D D$ and $L_i = 0$).[6]

The before-taxes utility ratio given in Equation (8) is proportional to the sum of a utility-increasing ($\phi_k w(1-\tau_w^0)$) and a utility-reducing term ($-D_0 p_D$) with $k = i$, divided by the same sum with $k = j$. In the proof we show that recycling the carbon revenue as in Equations (9) and (10) increases the utility-reducing term more strongly than the utility-increasing term, which makes the policy regressive.

Proof. For the proof of part (a), it suffices to demonstrate that $(U_i/U_j)^{\text{AT-P}} < (U_i/U_j)^{\text{BT}}$ for $\phi_j > \phi_i$.

By introducing the auxiliary variables A and B we transform Equation (9) into

$$\left(\frac{U_i}{U_j}\right)^{\text{AT-P}} = \left(\frac{\phi_j}{\phi_i}\right)^{\gamma}\left(\frac{\phi_i A(1+\frac{B}{A}) - D_0 p_D(1+\tau)}{\phi_j A(1+\frac{B}{A}) - D_0 p_D(1+\tau)}\right), \tag{12}$$

with $A = w(1-\tau_w^0)$ and $B = \tau p_D D$.

Similarly $\left(U_i/U_j\right)^{\text{BT}}$ can be transformed:

$$\left(\frac{U_i}{U_j}\right)^{\text{BT}} = \left(\frac{\phi_j}{\phi_i}\right)^{\gamma}\left(\frac{\phi_i A - D_0 p_D}{\phi_j A - D_0 p_D}\right).$$

We can ignore the constant term $(\phi_j/\phi_i)^{\gamma}$ which appears in both utility ratios. It hence suffices to work with the second term. In both the numerator and the denominator of Equation (12), a positive and a negative term remain. The positive term increases in B/A, which increases the utility ratio (and thus decreases inequality). Similarly, the negative term ($-D_0 p_D$) increases in τ, which decreases the utility ratio (and thus increases inequality). We can infer from this expression directly that the distributional effect of a carbon tax reform is neutral if $B/A = \tau$, since in that case the term $(1+\tau)$ can be eliminated from the fraction and we get $(U_i/U_j)^{\text{AT-P}} = (U_i/U_j)^{\text{BT}}$. The distributional effect of a tax reform is regressive if $B/A < \tau$ and vice versa. It thus remains to show that $B/A < \tau$. By inserting the expressions for A and B, we get

$$\frac{B}{A} = \frac{\tau p_D D}{w(1-\tau_w^0)} < \tau.$$

[6] Some argue that using carbon tax revenues for rebates in a pre-existing income tax system does not only reduce pollution but also enhances efficiency (Goulder, 1995; Bovenberg, 1999). Proposition 1 (b) implies that reaping such an additional benefit might come at the cost of increased inequality (at least if the tax cut is linear).

By rearranging, we obtain:

$$p_D D < w(1-\tau_w^0).$$

The term on left-hand side of this inequality represents total spending on polluting goods (before the tax reform), the term on the right-hand side stands for total income when aggregate leisure is zero (before the tax reform). Since by assumption ϕ_i is strictly smaller than ϕ_j, households with $j > 1$ always consume positive amounts of leisure and of the clean good. Total spending on polluting goods hence must be lower than total income (when no leisure is consumed) and the inequality above holds. This implies that $(U_i/U_j)^{\text{AT-P}} < (U_i/U_j)^{\text{BT}}$, and closes the proof of part (a).

The proof of part (b) is analogous to that of part (a), using $B = w\tau_w$ instead. What remains to show is that $B/A < \tau$. By inserting the expressions for A and B we get:

$$\frac{B}{A} = \frac{\tau_w}{(1-\tau_w^0)} < \tau. \tag{13}$$

For revenue recycling through income tax cuts, the sum of all income tax rebates equals the total carbon tax revenue: $\tau_w w \sum_{i=1}^N \phi_i(1-l_i) = \tau p_D D$. We use this relationship to eliminate τ_w from Equation (13) and obtain:

$$\frac{B}{A} = \frac{\tau p_D D}{(1-\tau_w^0) w \sum_{i=1}^N \phi_i(1-l_i)} < \tau.$$

By rearranging, we get:

$$p_D D < (1-\tau_w^0) w \sum_{i=1}^N \phi_i(1-l_i).$$

The term on the left-hand side of this inequality stands for total spending on polluting goods (before the tax reform), the term on the right-hand side for total income (before the tax reform). For the same reason as in the proof of part (a), this inequality holds. □

Proposition 2. *The tax reform is* progressive *for uniform lump-sum redistribution of the revenues (that is $L_i = L = \tau p_D D/N$ for $i = 1, \ldots, N$ and $\tau_w = 0$).*

The intuition behind the subsequent proof is similar to the intuition behind the proof of Proposition 1: in the case of a carbon tax with uniform lump-sum recycling, a positive (utility-enhancing) and a negative (utility-reducing) term are added to the numerator and the denominator of the before-taxes utility ratio $\left(U_i/U_j\right)^{\text{BT}}$. Since the transfers are uniform, these terms are constant across households. We demonstrate that the sum of both terms is positive, which reduces inequality.

Proof. Two terms are added to both the numerator and the denominator of the before-taxes utility ratio $\left(U_i/U_j\right)^{\text{BT}}$ to obtain the after-taxes utility ratio $\left(U_i/U_j\right)^{\text{AT-U}}$: $-D_0 p_D \tau < 0$ stands for a decrease in utility due to the tax on subsistence consumption and $\tau p_D D/N > 0$ stands for an increase in utility due to the revenue recycling. Adding up these two terms yields:

$$\tau p_D D/N - D_0 p_D \tau = p_D \tau (D/N - D_0) > 0.$$

This expression is strictly bigger than zero since we assume that τ, $p_D > 0$ and $\phi_i < \phi_j$. Therefore all agents with $j > 1$ have a level of polluting consumption that is higher than the subsistence level D_0, so the average level of polluting consumption, D/N, is always higher than the subsistence level D_0. The proof is then completed by using the elementary relation

$$m < s \Rightarrow \frac{m}{s} < \frac{m+t}{s+t}, \quad \text{for} \quad t > 0 \quad \text{and} \quad m, s > 0,$$

with $m = \phi_i w(1-\tau_w^0) - D_0 p_D$, $s = \phi_j w(1-\tau_w^0) - D_0 p_D$ and $t = -D_0 p_D \tau + \tau D p_D / N$.

□

Proposition 3. *For a subsistence level of polluting consumption of zero ($D_0 =$ 0), the revenue-recycling mechanisms examined in Proposition 1 are* distribution-neutral.

Proposition 3 demonstrates that it is only our assumption of a subsistence level of polluting consumption that drives the results of Proposition 1. The result presented in Proposition 2 is independent of the level of D_0.

Proof. Setting $D_0 = 0$ in Equations (8), (9) and (10) yields the desired result.

□

4 Conclusion

In this note we demonstrate conceptually that carbon-intensive subsistence consumption is the key to understanding the distributional effects of a carbon tax reform. We confirm that such a reform is regressive if revenues are recycled by lump-sum transfers that are in proportion to the households' productivities, and if revenues are recycled via linear income tax cuts. By contrast, a carbon tax reform can be made progressive by recycling the revenues as *uniform* lump-sum transfers. No additional assumptions are required to obtain our analytical results, which makes the modeling strategy transparent and our results robust.

Several extensions of our framework are conceivable, but go beyond the scope of this letter. Examples include non-linear income tax reductions, price effects and taxing emissions instead of output. We treat these cases in a numerical study (Klenert et al., 2015). Moreover, long-term consequences of a carbon tax reform would need to be studied in a model with structural change so that a decarbonization of the economy is possible.

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References

Bovenberg, A. L., 1999. Green Tax Reforms and the Double Dividend : an Updated Reader's Guide. International Tax and Public Finance 6, 421–443.

Chiroleu-Assouline, M., Fodha, M., 2014. From regressive pollution taxes to progressive environmental tax reforms. European Economic Review 69, 126–142.

Combet, E., Ghersi, F., Hourcade, J. C., Théry, D., 2010. Carbon Tax and Equity: The Importance of Policy Design. In: Dias Soares, C., Milne, J., Ashiabor, H., Deketelaere, K., Kreiser, L. (Eds.), Critical Issues in Environmental Taxation vol. VIII, pp. 277–295.

Cremer, H., Gahvari, F., Ladoux, N., 1998. Externalities and optimal taxation. Journal of Public Economics 70, 343–364.

Dissou, Y., Siddiqui, M. S., 2014. Can carbon taxes be progressive? Energy Economics 42, 88–100.

Flues, F., Thomas, A., 2015. The distributional effects of energy taxes. OECD Taxation Working Papers 23.

Fullerton, D., 2011. Six distributional effects of environmental policy. Risk analysis 31(6), 923–9.

Fullerton, D., Monti, H., 2013. Can pollution tax rebates protect low-wage earners? Journal of Environmental Economics and Management 66(3), 539–553.

Goulder, L. H., 1995. Environmental taxation and the double dividend: A reader's guide. International Tax and Public Finance 2(2), 157–183.

Grainger, C. A., Kolstad, C. D., 2010. Who Pays a Price on Carbon? Environmental and Resource Economics 46(3), 359–376.

Jacobs, B., De Mooij, R., 2015. Pigou meets Mirrlees: on the irrelevance of tax distortions for the second-best Pigouvian tax. Journal of Environmental Economics and Management 71, 90–108.

Kaplow, L., 2012. Optimal control of externalities in the presence of income taxation. International Economic Review 53(2), 487–509.

Klenert, D., Schwerhoff, G., Edenhofer, O., Mattauch, L., 2015. Carbon taxation, inequality and Engel's law – the double dividend of redistribution. Under review.

Rausch, S., Metcalf, G. E., Reilly, J. M., 2011. Distributional impacts of carbon pricing: A general equilibrium approach with micro-data for households. Energy Economics 33, S20–S33.

Rausch, S., Reilly, J. M., Metcalf, G. E., Paltsev, S., 2010. Distributional Implications of Alternative U . S . Greenhouse Gas Control Measures. The B.E. Journal of Economic Analysis & Policy 10(2).

Sterner, T., 2011. Fuel Taxes and the Poor: The Distributional Effects of Gasoline Taxation and Their Implications for Climate Policy. Johns Hopkins University Press.

Tietenberg, T. H., 1990. Economic Instruments for Environmental Regulation. Oxford Review of Economic Policy 6(1), 17–33.

Wier, M., Lenzen, M., Munksgaard, J., Smed, M., 2001. Effects of Household Consumption Patterns on CO_2 Requirements. Economic Systems Research 13(3).

Chapter 3

Environmental Taxation, Inequality and Engel's Law: The Double Dividend of Redistribution[1]

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Environmental Taxation, Inequality and Engel's Law: The Double Dividend of Redistribution

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Abstract

Empirical evidence shows that low-income households spend a high share of their income on pollution-intensive goods. This fuels the concern that an environmental tax reform could be regressive. We employ a framework which accounts for the distributional effect of environmental taxes and the recycling of the revenues on both households and firms to quantify changes in the optimal tax structure and the equity impacts of an environmental tax reform. We characterize when an optimal environmental tax reform does not increase inequality, even if the tax system before the reform is optimal from a non-environmental point of view. If the tax system before the reform is calibrated to stylized data – and is thus non-optimal – we find that there is a large scope for inequality reduction, even if the government is restricted in its recycling options.

JEL classification: D58, D62, E62, H21, H23

Keywords: environmental tax reform, double dividend, revenue recycling, inequality, distribution, non-homothetic preferences

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1 Introduction

A widespread reservation against environmental taxation is that this policy might increase inequality (Bento et al., 2005; Bento, 2013; Wier et al., 2005) at least in developed countries.[1] A major reason why this policy is considered regressive is that poor households spend a larger fraction of their income on pollution-intensive goods than rich households. This is reminiscent of Engel (1857)'s work on subsistence levels of food consumption. In principle, the environmental tax revenue can be recycled in a progressive way. However, it is unclear to what extent the recycling of the tax revenue can offset the regressive effect of the tax itself.

The main novelty of this article is that we quantify the distributional effect of *optimal* environmental tax reforms. We also compare different recycling mechanisms for environmental tax revenue in terms of their equity implications. For this purpose, we analyze an increase in regressive environmental taxes which is induced by a change in preferences for environmental quality. We assume that the government has different options for recycling the tax revenue such as linear/non-linear income tax cuts and uniform lump-sum transfers. We determine the distributional effects of such a tax reform by comparing different economic variables before and after the tax reform in two settings: first, in a setting in which taxes are set optimally before the tax reform (from a non-environmental point of view); second, in a calibrated setting in which the initial tax system is suboptimal. We find that the overall distributional impact of such a reform depends on the initial tax structure and the available revenue recycling options.

Specifically, our main findings are: (i) If the pre-existing tax system is optimal, the regressive effect of the environmental tax can be largely or even completely offset by the recycling of the tax revenue: an environmental tax reform is even slightly progressive if the government can use a combination of lump-sum transfers and non-linear income tax cuts to redistribute the tax revenue. If uniform lump-sum transfers are unavailable for redistribution, the tax reform is slightly regressive. (ii) If the pre-existing tax system is non-optimal, an environmental tax reform can have a large scope for inequality reduction.

In the cases in which inequality is reduced through an environmental tax reform, we talk about a *double dividend of redistribution*. Our double dividend of redistribution, however, is different from the classical double dividend (Goulder, 1995; Bovenberg, 1999).[2] The reason is that in a setting with heterogeneous households, the classical double dividend is of limited interest, since constraining the government to using either income tax cuts or uniform lump-sum transfers for revenue recycling will inevitably lead to welfare losses. In fact, we show that an optimal environmental tax reform requires adjustments in both lump-sum and income taxes.

[1]We are only concerned with the (intra-generational) distribution between different households at a given point in time, since increased intra-generational inequality is one of the most commonly used arguments against environmental policy (Combet et al., 2010; Ekins, 1999). For an article that considers both intra- and inter-generational distributional effects of environmental taxation see Jacobs and van der Ploeg (2010).

[2]In this strand of literature it is argued that using environmental tax revenue for reducing distorting taxes might lead to a reduction in the gross costs of an environmental tax reform, compared to lump-sum recycling (Goulder, 1995; Bovenberg, 1999).

There are two separate strands of literature which analyze questions of (optimal) taxation and distribution in the presence of (environmental) externalities: First, the optimal taxation literature, which models pollution as a by-product of the consumption of polluting goods and an environmental tax hence as a tax on the polluting commodity. Models in this strand of the literature assume linear production functions which lead to constant prices (with the exception of Cremer and Gahvari 2001). The second strand analyzes the effect of increased environmental taxes on factor prices (and sometimes on the distribution between heterogeneous households). These publications, however, are not concerned with the optimality of the tax system.

The optimal taxation literature analyzes questions such as under what conditions the second-best externality tax can be set to the first-best Pigouvian level, when it suffices to set linear corrective taxes, if income and commodity taxes can be formulated independently of externality-correcting taxes[3] and if the optimal (income, commodity and environmental) tax rules change in a second-best setting. This literature, however, does not make statements about the distributional effects of an optimal environmental tax reform.

The conclusions from these studies differ, depending on the tax instruments available to the government: Jacobs and De Mooij (2015) show that when the income and the externality tax are both linear or both non-linear, and uniform lump-sum taxes are available, the government should set the externality tax at its Pigouvian level; optimal income and optimal environmental taxes can be determined independently.[4] Cremer et al. (1998) demonstrate, in a setting in which uniform lump-sum transfers are not available, that this does not hold anymore for the combination of linear externality taxes with non-linear income taxes and that the additivity property breaks down in this case. Still excluding price effects, Kaplow (2012) analyzes different environmental tax reform designs under equity constraints.

When the production side is accounted for explicitly, as is done in the second strand of the literature, substitution effects between pollution and other factors of production occur, that do not exist when prices are assumed to be constant (Fullerton et al., 2001; Dissou and Siddiqui, 2014). In fact, Fullerton and Heutel (2007, 2010) show that the incidence of an environmental tax on the firm side can have strong distributional effects. Dissou and Siddiqui (2014) demonstrate that these effects are likely to be progressive.

Both strands of literature have gained important insights, but they are also of limited applicability: Regarding optimal taxation, statements about changes in abstract tax rules and an exclusive focus on households do not suffice to make quantitative statements about the distributional effects of environmental tax reforms. On the other hand, models from the second strand of the literature often do not account for heterogeneous households (and thus for non-linear income taxes) and they analyze tax reforms away from the optimum. If they account for heterogeneity the latter point of critique still holds (Chiroleu-

[3]Sandmo (1975) called this principle the *additivity property*.

[4]This contribution and related research is centered around the question whether the marginal cost of public funds equals unity or not. Kaplow (2004) was the first to argue that these are indeed equal to one, if Mirrleesian income taxes and optimal public good supply are set simultaneously. Jacobs and De Mooij (2015) extend Kaplow's thesis to the case of Pigouvian taxes combined with optimal income distribution. This holds when uniform lump-sum transfers are available to the government, in which case there are no environmental double dividends possible.

Assouline and Fodha, 2014; Fullerton and Monti, 2013; Klenert and Mattauch, 2016).

Our study bridges the gap between these two strands: we present a hybrid model in which the modeling of the household side is based on the first and the modeling of the firm side is based on the second strand of the literature. The government is modeled as a Stackelberg leader which anticipates the actions of the other agents, while these agents take the policies imposed by the government as given. Solving this model numerically, we illustrate the distributional consequences of such a tax reform by quantifying the changes in the tax rates and in inequality.

We use the following assumptions from the aforementioned studies, which we consider the most empirically relevant, to extend the small analytical model described in Klenert and Mattauch (2016) to a numerical model which includes prices effects and determines optimal policies: First, as Fullerton and Heutel (2007, 2010), we model pollution as a production input, and an environmental tax hence as a tax on this input (and not on the polluting commodity). Second, we focus on the case of a non-linear income tax combined with a linear tax on pollution, to account for the redistributive role of income taxes and since the pollution tax is levied directly in production. Third, we determine optimal policies as in Cremer et al. (1998); Cremer and Gahvari (2001) and Jacobs and De Mooij (2015). Finally, we focus on the case of a non-homothetic utility function to reflect the empirical finding that poor households spend a higher share of their income on pollution-intensive goods (Grainger and Kolstad, 2010; Levinson and O'Brien, 2015; Flues and Thomas, 2015). Note that these findings mainly concern developed countries: in developing countries an environmental tax can have a less regressive or even a progressive effect (Sterner, 2011). The present study is the first to combine these assumptions.

The remainder of this article is structured as follows: The model is outlined in Section 2, which also includes subsections on the calibration of the model and its numerical solution. We describe the adjustment in the optimal income and lump-sum taxes that accompany an optimal environmental tax reform in Section 3. In Section 4, we modify some of the modeling assumptions such as the tax instruments available to the government, the assumption of non-homothetic preferences and values of key parameters. In Section 5 we apply the framework from the preceding sections to a calibrated economy. We show that, if the pre-existing tax system is suboptimal, there is a large scope for inequality reduction. Section 6 concludes.

2 The model

We use a two-sector general-equilibrium model with Mirrleesian income taxation, in which N households are distinguished by their productivity. Households consume two goods with different pollution intensities. There is a subsistence level of polluting consumption, which we model with a Stone-Geary utility function. Households derive utility from consumption of the two goods, leisure and environmental quality. Individual households cannot affect pollution, so only the government can regulate it. Within this framework we assess the distributional effects of an optimal environmental tax reform.

Firms: There are two representative firms, one produces a clean consumption good C, the other produces a polluting consumption good D. Pollution Z is a by-product of production. We assume that production $F_j(T_j, Z_j)$, with $j \in \{C, D\}$, is a function of pollution Z_j and a resource T_j, which is bought from the households.[5] The resource T_j can, in our model, be interpreted as a fixed amount of a tradable resource such as labor, land or capital. In that sense leisure is the amount of this resource which is used at home. For the sake of simplicity we will refer to the resource sold to the firm as labor and to the resource used at home as leisure.

Firms produce with a constant returns to scale technology $F_j(T_j, Z_j)$, $j \in \{C, D\}$:

$$F_j(T_j, Z_j) = \begin{cases} (\varepsilon_j T_j^r + (1-\varepsilon_j) Z_j^r)^{(\frac{1}{r})}, & \text{if } Z_j \leq x T_j \\ 0, & \text{if } Z_j > x T_j \end{cases} \tag{1}$$

with $\sigma = 1/(1-r)$ being the elasticity of substitution between labor and pollution Z_j and ε_j the factor share in the respective sectors. The additional inequality (with $x > 0$) in the production function implies that the firms allocate some of their labor to production and the rest to pollution abatement activities (see Appendix A in Copeland and Taylor 1994 for more details). The firms sell their good at price p_j and pay wages w for the production factor T_j.

The firms choose their production factors so as to equalize factor payments with marginal productivities:

$$w = \frac{\partial F_j(T_j, Z_j)}{\partial T_j} \tag{2}$$

and

$$\tau_Z = \frac{\partial F_j(T_j, Z_j)}{\partial Z_j}, \tag{3}$$

with τ_Z denoting a pollution tax levied by the government.

Households: Households are distinguished only in their productivity ϕ_i. There are N households, ordered from 1 for lowest to N for highest productivity. Households all have the same total time endowment T, which they can either dedicate to leisure l_i or to production. Each household receives an after tax income of

$$I_i = (1-\tau_{w,i})\phi_i w (T - l_i). \tag{4}$$

with $\tau_{w,i}$ representing non-linear income taxes, levied by the government. We follow Ballard et al. (2005) in modeling the fact that households need a minimal level of polluting consumption D_0, with non-homothetic preferences. All households have the same preferences and maximize the following utility function:

$$V_i = U(C_i, D_i, l_i) + E(Z) = C_i^{\alpha}(D_i - D_0)^{\beta} l_i^{\gamma} + (E_0 - \xi(Z_C + Z_D)^{\theta}), \tag{5}$$

with the environmental quality E(Z) being defined as

$$E(Z) = E_0 - \xi(Z)^{\theta}, \qquad \text{with} \qquad Z = Z_C + Z_D. \tag{6}$$

[5]This is a common approach when assessing the equity and efficiency impacts of environmental policy in a general equilibrium (see e.g. Fullerton and Heutel 2007; Fullerton and Metcalf 2001; Copeland and Taylor 1994).

E_0 is the initial stock of environmental quality which suffers damages from total pollution Z emitted in the production sectors.

The budget equation of each household is given by

$$C_i \cdot p_C + D_i \cdot p_D = I_i + L. \tag{7}$$

Here, L is a uniform lump-sum transfer (or, if negative, a linear lump-sum tax).[6] Each household chooses its leisure time share and consumption in both goods to maximize the utility function with respect to the budget equation, which yields the following first-order conditions:

$$\left(\frac{\partial U_i}{\partial C_i}\right) \Big/ \left(\frac{\partial U_i}{\partial D_i}\right) = \frac{p_C}{p_D}, \tag{8}$$

$$\left(\frac{\partial U_i}{\partial D_i}\right) \Big/ \left(\frac{\partial U_i}{\partial l_i}\right) = \frac{p_D}{(1-\tau_{w,i})\phi_i w}. \tag{9}$$

Government: The government maximizes total welfare W, i.e. the sum of all agents' utilities:

$$W = \sum_{i=1}^{N} V(C_i, D_i, l_i, E). \tag{10}$$

Taxes are primarily used to finance the government's revenue requirement G, which remains constant during the analysis. The government's budget equation is thus given by:

$$G = -NL + \sum_{i=1}^{N} \tau_{w,i}\phi_i w(T - l_i) + \tau_Z(Z_C + Z_D). \tag{11}$$

We assume that the government is unable to observe the individual productivity of each household. To ensure that agent i prefers his bundle $\{C_i, D_i, I_i\}$ to the bundles of all other agents $j \neq i$, we implement the following Mirrlees (1971) type incentive compatibility constraint:

$$U_i \geq U_i^j. \tag{12}$$

U_i^j is the utility of household i pretending to be household j. It is given by

$$U\left(C_j, D_j, T - \frac{I_j}{(1-\tau_{w,j})\phi_i w}\right). \tag{13}$$

The optimal income tax system is a result of the welfare maximization and the incentive constraints: the government chooses the income tax rates such that there is some redistribution between agents (due to the utilitarian welfare maximization), but not enough to destroy the agents' incentives to work (due to the incentive constraints).

[6]Following Jacobs and De Mooij (2015), we include uniform lump-sum transfers as a possible policy instrument. We analyze the case of a government restricted to income taxes in Section 4.1 and find that the uniform lump-sum transfers play a significant role in optimal taxation.

Resource constraints and numeraire: The following resource constraints apply:

$$T_C + T_D = \sum_{i=1}^{n} \phi_i (T - l_i), \tag{14}$$

$$p_C \sum_{i=1}^{n} C_i + \frac{1}{2} G = F_C p_C, \tag{15}$$

$$p_D \sum_{i=1}^{n} D_i + \frac{1}{2} G = F_D p_D. \tag{16}$$

The first equation describes the equilibrium on the labor market, while the last two equations describe the equilibrium in the market for clean and polluting goods. The government is assumed to consume equal shares of clean and polluting goods. We set the price w of the production input T_j as the numeraire.

2.1 Calibration

For the simulations below we set $N = 5$. The individual productivities are calibrated to match recent U.S. data on the income shares of different quintiles (see Table 1).

Quintile	1	2	3	4	5
Productivity (ϕ_i)	0.03	0.0825	0.141	0.229	0.511

Table 1: The households' productivities are calibrated to match data from the U.S. Census Bureau on the income shares of different quintiles in the benchmark scenario (DeNavas-Walt et al., 2012)

The remaining parameters are chosen as displayed in Table 2. We choose the clean and the polluting consumption shares in the utility function in relation to the share of clean and polluting output produced (as do Fullerton and Heutel 2007 and Goulder et al. 1999). The polluting sector is more pollution-intensive than the clean sector, which we assume to be almost pollution-free. We set D_0 such that it is at 44 % of the mean polluting consumption level and at 62 % of the polluting consumption level of the lowest income quintile before the tax reform. Government spending G is set at roughly 24 % of the GDP before the tax reform. We vary this value in Section 4.3 between 0 and 70 % of GDP and find that it does not change the results qualitatively.

2.2 Solving numerically

We need to use numerical methods to solve the model for the following reasons: First, we calibrate the model to stylized data on income distribution and tax burden and calculate the change in optimal tax rates instead of tax rules to quantify the distributional effects of an environmental tax reform. Second, we model the production side to include price effects and an environmental tax as a tax on pollution which occurs in the production sector. Third, the government in our model acts as a Stackelberg leader, which means it anticipates the actions of all other actors, including firms, while firms and households take the actions of the government as given.

Households		
α	clean consumption share in utility	0.7
β	polluting cons. share in utility	0.2
γ	leisure share in utility	0.2
D_0	subsistence level poll. consumption	0.5
θ	damage exponent	1.0
ξ	pref. for env. quality	0.1
Firm		
A_C, A_D	total factor productivity	1
ε_C	labor intensity clean production	0.995
ε_D	labor intensity poll. production	0.92
σ	elast. of subs. btw. labor and pollution	0.5
Government		
G	government consumption	5

Table 2: Calibration of the model parameters

The variables C_i, D_i, l_i, p_C, p_D, T_C, T_D, Z_C, Z_D, L, τ_Z and $\tau_{w,i}$ are determined, in the general equilibrium, by the following optimization: We use the algebraic modeling system GAMS (Rosenthal, 2014) to maximize total welfare (10) subject to the government's budget constraint (11), the incentive constraints (12), the resource constraints (14)-(16) and to the first-order conditions of the firms (2),(3) and the households (7)-(9), by varying the available policy instruments.

2.3 Measures of distribution

Since the pollution tax is levied on the firm side, we need a measure of distribution which also includes price effects on consumption goods and effects on leisure, which occur when both leisure and pollution are an input in production. Traditional measures such as the Gini coefficient in income are hence not suitable for our purpose. An alternative is calculating the Gini coeffient in utility: this includes both price effects and changes in leisure levels. In the following, whenever we refer to the Gini coefficient, we refer to the Gini coefficient in utility. We use the non-environmental utility U for the calculation of the Gini coefficient in order to separate the inequality-reducing effect of avoided damages from the distributional effect of the environmental tax incidence and the revenue redistribution.[7]

3 Optimal environmental tax reform

In this section we determine the optimal mix of non-linear income taxes, uniform lump-sum transfers and (linear) taxes on the polluting production input

[7]Bovenberg and van der Ploeg (1994, 1996) use the terms "blue welfare" for the non-environmental welfare component, and "green welfare" for the welfare component that depends on the environmental quality, to make this important distinction. Bovenberg and van der Ploeg (1996) and Ligthart and van der Ploeg (1999), further decompose welfare in a red and a pink component which accrue to changes in public consumption and employment, respectively. Since we assume constant government spending and full employment, there are no effects on public consumption or employment in our model.

before and after an increase in the preference parameter for environmental quality ξ from zero to $\xi > 0$. This increase can, for instance, be interpreted as new scientific evidence on the detrimental effects of pollution on well-being. We call the adjustment of the policy instruments an optimal environmental tax reform (ETR).

The government can adjust the optimal tax and transfer levels freely. This setting is hence the most unrestricted one we analyze. In the subsequent sections we will gradually introduce more government constraints (non-availability of lump-sum transfers in Section 4.1 and a suboptimal initial tax system and fixed ETR designs in Section 5). By comparing these sections to the current section the implication of each constraint becomes visible.

In this section, we obtain the following results: First, optimal income taxes hardly react to a change in environmental preferences (see Figure 1, top left). Second, most additional revenue is redistributed in a lump-sum fashion (see Figure 1, top right). Third, the Gini coefficient decreases (see Figure 1, bottom left) and fourth, the government shifts away from lump-sum towards environmental taxes in the financing of its spending (see Figure 1, bottom right).

We first describe the economy before the tax reform. The fixed government spending requirement is financed in large parts by lump-sum and income taxes, which are set such that the incentive constraints are binding. A smaller fraction is contributed by environmental taxes. Optimal environmental taxes are greater than zero even in the case of $\xi = 0$ because only from a certain environmental tax threshold on the firm will reduce production in response to the environmental tax. Even a government without a preference for environmental quality sets the environmental tax just below this threshold level because this does not distort production.[8]

We now detail the results: First, before ξ is increased, the income taxes are adjusted such that welfare is maximized and the incentive constraints are not violated. Due to the high marginal utility of consumption of low-income households, we see high subsidies for low-income households and high-taxes for high-income households. The income tax system hardly changes in response to an ETR since a more progressive change in the tax system would violate at least one of the incentive constraints (Figure 1, top left).

Second, lump-sum transfers are mainly a tool for balancing the government's budget: before the ETR they are negative. After the tax reform, when the government can meet a large part of its spending requirements with environmental taxes, lump-sum transfers are used for returning the excess revenue to the households (Figure 1, top right). Since the income taxes are already set such that the incentive constraints are binding, more redistribution is only possible through lump-sum transfers. Therefore the overall effect of the ETR is slightly progressive.

The result concerning the Gini coefficient is a consequence of several opposing effects: on the one hand, an environmental tax has a regressive effect, since it increases the price of the polluting subsistence good relative to the price of the cleaner good. Poor households are hit disproportionally hard by this tax, since they spend a higher share of their income on polluting goods, due

[8]This threshold level is a consequence of the assumption that the firms allocate some of the labor to pollution abatement (see Equation (1) and the subsequent paragraph). In Figure 4 in Section 4.3 we gradually increase ξ from zero and hence demonstrate the existence of that threshold.

to our assumption of non-homothetic preferences. On the other hand, the environmental tax creates revenues which are used for redistributive purposes: the regressive lump-sum tax is abandoned. Instead, progressive lump-sum transfers are put into place. Due to the progressive effect of the lump-sum transfers, distortionary labor subsidies for the low-income quintile and distortive income taxes for the high income quintiles can be reduced (slightly). The overall result is a reduction in the Gini coefficient (Figure 1, bottom left).[9]

Fourth, increasing the preference for environmental quality leads to an increase in the environmental tax and hence to an increase in the share of environmental tax-financed government spending. As a consequence, income taxes are slightly reduced and lump-sum taxes are completely eliminated (Figure 1, bottom right).

In sum, these results demonstrate that if a tax system is already optimal (from a non-environmental view, i.e. when $\xi = 0$), an increase in the preference parameter for environmental quality ξ leads to a readjustment of optimal lump-sum transfers and income tax rates that renders the new tax system more progressive. A government, in our model, can thus use the additional revenue generated by environmental taxes to optimally adjust the tax system in a progressive way. We hence obtain a double dividend of redistribution even if the pre-existing tax system is optimal from a non-environmental point of view.

Our results quantify the impact of an optimal environmental tax reform not only on inequality, but also on optimal income tax rates and lump-sum transfers. We thus complement the optimal taxation literature by quantifying the change in the tax rates for different quintiles, instead of calculating the changes in abstract tax rules.

[9] We use the Gini coefficient in non-environmental utility, see Section 2.3 for more details.

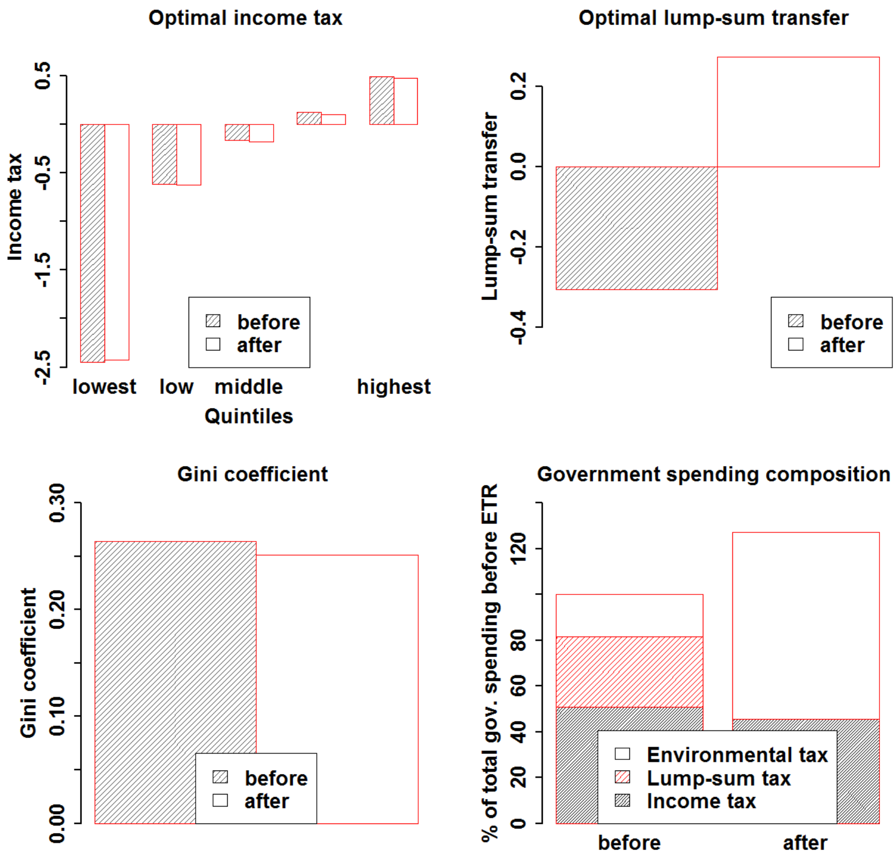

Figure 1: Optimal non-linear income and lump-sum taxes, as well as the Gini coefficient and the government spending composition before and after an environmental tax reform. Government spending increases after the environmental tax reform since lump-sum transfers (which we include in the government spending) increase.

4 Robustness: lump-sum transfers, subsistence consumption and greening of preferences

This section includes additional experiments to facilitate the comparison of our results to the literature on optimal taxation in the presence of an environmental externality. Furthermore, it illustrates the consequences of the different modeling choices. In Section 4.1 we analyze the case in which uniform lump-sum transfers are unavailable to the government (a common assumption in the literature). In Section 4.2, we analyze the role of non-homothetic preferences by setting the subsistence level D_0 to zero in all scenarios (i.e. in Sections 3 and 4.1). In Section 4.3 we vary critical parameters to analyze our results for robustness.

Detailed results and the differences to Section 3 are elucidated in more detail in the individual sections.

4.1 Optimal taxation without lump-sum transfers

Most articles have not considered the possibility of *uniform* lump-sum transfers in an optimal taxation setting in the presence of an externality. Jacobs and De Mooij (2015) is one of the few exceptions that allow for uniform lump-sum transfers. We analyze the effect of this assumption in the current section, by performing the same analysis as in Section 3 without the possibility of optimally set uniform lump-sum transfers (taxes).[10]

We find that an increase in the preference parameter for environmental quality ξ leads to the following effects: First, since lump-sum taxes are not available to the government, redistribution of additional revenue occurs only through the income tax system. Optimal income taxes hence react strongly to a change in environmental preferences (see Figure 2, top left). Second, this leads to a shift in the composition of government spending from income towards pollution taxes (see Figure 2, bottom). Finally, the Gini coefficient increases by more than 1 % (see Figure 2, top right).

Before the environmental tax reform, the fixed government spending requirement is financed in large parts by income taxes which are set such that the incentive constraints are binding. A smaller fraction is contributed by environmental taxes. Optimal environmental taxes are greater than zero for the same reason as in Section 3.

Setting $\xi > 0$ (and above the threshold value described in Section 4.3) creates additional environmental tax revenue which is used to lower distorting taxes. However, since the income taxes are already set such that the incentive constraints are binding, a tax cut must always involve all households – otherwise the incentive constraints would be violated. Subsidies for low-income households increase strongly, and income taxes for high-income households decrease more moderately – this increases the inefficiency in the tax system. In sum, these effects lead to an increase in the Gini coefficient, since the regressive effect of the environmental tax cannot be compensated completely by an optimal adjustment of the income taxes. Uniform lump-sum taxes are hence necessary to reduce inequality without violating the incentive constraints and to recycle the environmental tax revenue to the households in an efficient way.

[10]This means all equations laid out in Section 2 remain the same, but we add the constraint that $L = 0$.

Most of the differences to Section 3 are explained by the fact that the environmental tax revenue in the current section is redistributed via income tax cuts or income subsidies. Redistribution through the income tax system is more distortionary since the income taxes before the ETR are already set such that the incentive constraints are binding – the progressivity of the income tax system can hence not be increased further to offset the regressive effect of the environmental tax and the tax reform increases inequality. If instead lump-sum transfers are available, as in Section 3, the government can counteract the inequality-increasing effect of environmental taxes: uniform lump-sum transfers are progressive since richer households consume more of the polluting good in absolute terms and therefore pay more environmental taxes.

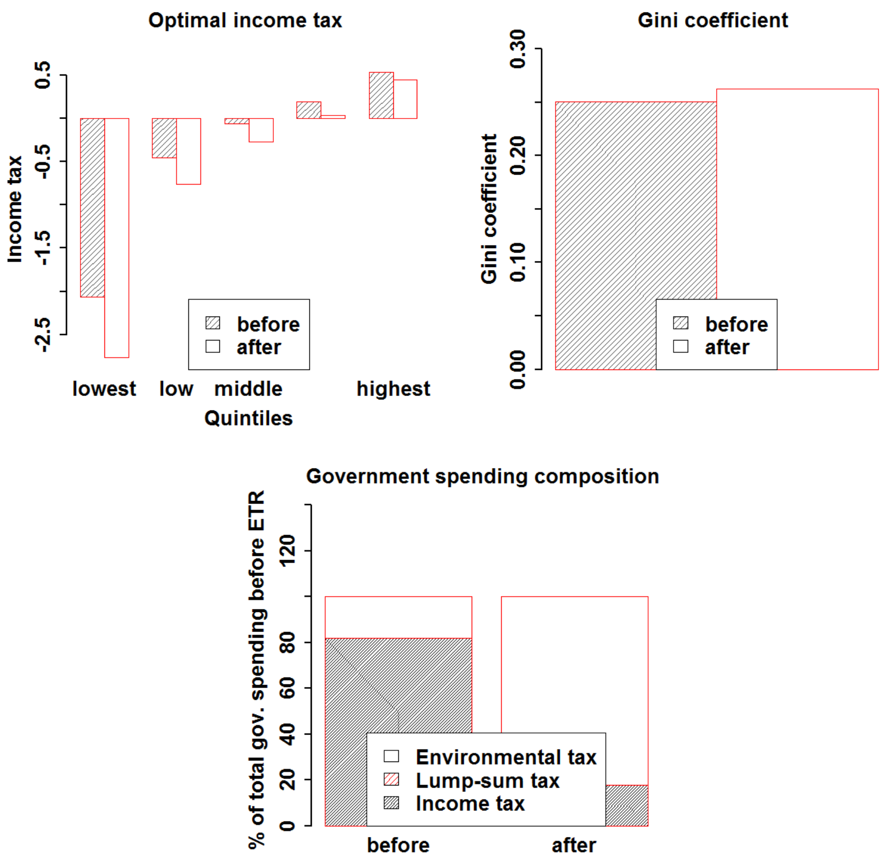

Figure 2: Optimal non-linear income taxes, the Gini coefficient and the government spending composition before and after an environmental tax reform when uniform lump-sum transfers are not permitted.

4.2 The role of non-homothetic preferences

In this section we set the subsistence level of polluting consumption to zero and hence abandon our assumption of non-homothetic preferences. The experiment remains the same as in Sections 3 and 4.1: by increasing the preferences for environmental quality from 0 to $\xi > 0$, we analyze the effect of an optimal environmental tax reform on tax and transfer levels, distribution and the composition of government financing. This section is hence analogous to Section 3, considering the case of homothetic preferences instead.

Non-homothetic preferences play an important role in our model: we use them to model the fact that an environmental tax is regressive due to the existence of a subsistence level of polluting consumption (D_0). The regressive effect can be seen by comparing the Gini coefficients in Figures 1 and 3. By setting the subsistence level to zero, we remove the regressive effect of environmental taxation.

We find that if the government can adjust income taxes and uniform lump-sum transfers optimally (as in Section 3), the results remain qualitatively unchanged (see Figure 3). In particular, inequality is still decreased by an optimal environmental tax reform. This is unsurprising, because we removed the mechanism responsible for the regressivity of the environmental tax.

We observe only small differences between an environmental tax reform when the environmental tax is assumed to be regressive (as in Section 3) and when an environmental tax is assumed to be neutral (as in the current section). This means that, if an optimizing government has access to both lump-sum and non-linear income taxes, an environmental tax reform, even if the environmental tax itself is assumed to be regressive, can be adjusted such that it is slightly progressive.

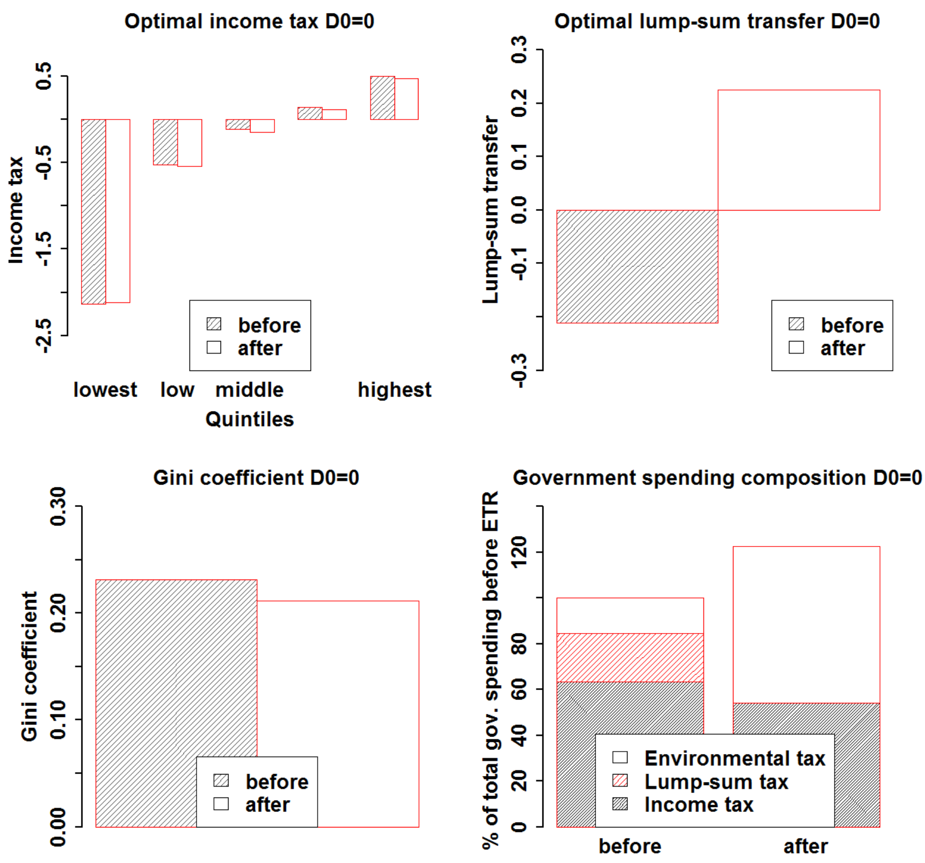

Figure 3: Optimal non-linear income and lump-sum taxes, as well as the Gini coefficient and the government spending composition before and after an environmental tax reform when preferences are homothetic (i.e. $D_0 = 0$).

4.3 Parameter sensitivity and greening of preferences

In this section we analyze the sensitivity of our main results in Section 3 to variations in key parameters such as the elasticity of substitution between labor and pollution (σ), the level of government spending (G), the share of labor in the polluting sector ε_D and the preference parameter for environmental quality (ξ). Except for an elasticity of substitution between labor and pollution above 0.98, we find that the results remain qualitatively unchanged. The detailed results of the sensitivity analysis are available upon request from the authors.

We vary σ, the elasticity of substitution between labor and pollution, between 0.2 and 0.999. We find that the changes in the optimal tax schemes remain qualitatively the same. However, the result concerning the Gini coefficient depends on σ: an environmental tax reform slightly reduces the Gini coefficient for σ between 0.2 and 0.98. It increases the Gini coefficient slightly if $\sigma \geq 0.99$. The detailed results are displayed in Table 3.

σ	Gini (before ETR)	Gini (after ETR)
0.2	0.2551	0.2358
0.5	**0.2644**	**0.2582**
0.8	0.2648	0.2633
0.999	0.2649	0.2650

Table 3: Sensitivity of the Gini coefficient from Section 3 to changes in the elasticity between labor and pollution. The highlighted case is our benchmark calibration.

We set the level of government spending G at 5 in the benchmark calibration (this corresponds to roughly 24 % of GDP before the tax reform). In order to assess the impact of varying this parameter, we analyze two extreme values: zero and 15. We find that the results do not change qualitatively. The level of government spending mainly influences the level of the lump-sum transfers: If $G = 15$, lump-sum transfers are negative, since the government uses them to raise revenue. If $G = 0$, lump-sum transfers are well above zero since they are used to return additional revenue to the households.

The share of labor in the polluting sector is $\varepsilon_D = 0.92$ in the benchmark scenario. The results concerning inequality and optimal income tax schedules do not change qualitatively when ε_D is varied. However, the government spending composition reacts strongly to this parameter: Lower values of ε_D (e.g. $\varepsilon_D = 0.7$) lead to a higher use of pollution in the production sector and thus to more government revenue through environmental taxes. This increase in government revenue induces a shift in the composition of government spending.

The effect of the preference for environmental quality can be illustrated by gradually increasing the parameter ξ. Figure 4 displays the optimal environmental tax as a function of ξ. For values of ξ between zero and 0.005, the environmental tax does not react to an increase in ξ. This explains the fact that a government sets a positive environmental tax even if $\xi = 0$: up to a certain threshold level the firms do not react to an increase in the environmental tax and the government hence sets the environmental tax at this level. This threshold level is a consequence of the assumption that the firms allocate some of the labor to pollution abatement (see Equation 1 and the subsequent paragraph).

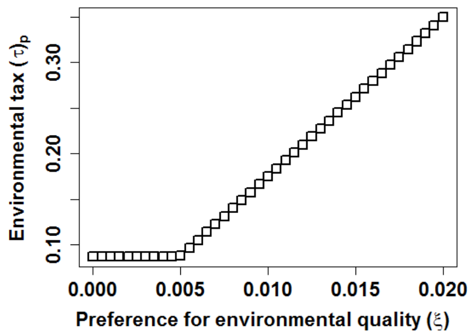

Figure 4: The effect of a gradual increase of the preference for environmental quality on the optimal environmental tax level. There is a threshold at ξ = 0.005 from which on the optimal environmental tax reacts to an increase in ξ.

5 The case of a calibrated pre-existing tax system

Recently, it has been of great concern that inequality rises to levels that may be harmful to societies (OECD, 2011): governments may fail to set taxes adequately to counteract undesirable levels of income inequality (Piketty, 2014).[11]

This section applies the theoretical framework from Section 3 to a real-world setting with suboptimally high inequality. Instead of comparing optimal taxation scenarios as in the preceding sections, we calibrate the model to the actual income tax schedule of the U.S. economy (see Section 5.1 for details on the calibration). This implies that in the initial scenario both the pollution externality is undertaxed and there is too little redistribution. This constitutes a very stylized scenario for examining real-world inequality levels. The purpose of this section is to give insights on actual policy debates about the distributional impacts of environmental tax reforms.

We additionally assume that the government is constrained to three realistic designs of an environmental tax reform: additional revenue can be recycled either via non-linear income tax cuts, via linear income tax cuts, or through uniform lump-sum transfers (the different scenarios are outlined in detail in Section 5.2).[12] Within this setting we compare the equity impacts of three designs of an ETR, when the preferences for environmental quality are increased from zero to $\xi > 0$.

Our main two results are as follows: First, we show that revenue recycling via non-linear income tax cuts and through uniform lump-sum transfers reduces inequality below initial levels. We call this effect the *double dividend of redistribution*. It occurs when inequality levels decrease through an environ-

[11]While some kinds of inequality may indeed be detrimental for society, others motivate people to work harder, and can be beneficial (Marrero and Rodríguez, 2013). However, there seems to be evidence that inequality itself can have a negative effect on efficiency (Berg et al., 2012; Kumhof et al., 2015). At least for this reason, assuming suboptimally high levels of inequality is thus a credible premise and inequality-reduction a frequent policy goal.

[12]We refrain from displaying the results of revenue recycling through a combination of lump-sum transfers and non-linear income tax cuts, since it leads to the same outcome as the scenario with only non-linear income tax cuts. The reason for that is that the government uses all the environmental tax revenue to mitigate inequality in the income tax system and hence has no use for lump-sum transfers.

mental tax reform.[13] Second, we demonstrate that the optimal environmental tax rate depends on how the environmental tax revenue is recycled. For detailed results see Section 5.3.

These results have strong political consequences: In a calibrated scenario, in which inequality is suboptimally high, and in which the government cannot observe the individuals' skill levels, a government should not set a lower-than-optimal environmental tax out of distributional concerns. The optimal tax we refer to is the optimal environmental tax from Section 3, in which the government adjusts income, lump-sum and environmental taxes simultaneously. Instead, a government should combine an optimal environmental tax with a progressive revenue-recycling mechanism, in order to reduce inequality and enhance environmental quality at the same time.

5.1 Calibration of the suboptimal income tax system

In this section, instead of determining the optimal income tax in the initial scenario, we use recent U.S. data on income taxation to perform a similar analysis as in Section 3 in a calibrated framework. The individual income tax rates are given in Table 4. These tax rates do not only include individual income taxes, but also corporate income taxes, social insurance taxes and excise taxes. For the sake of simplicity we refer to the sum of these taxes as the income tax. The remaining parameters are given in Section 2.1.

Quintile	1	2	3	4	5
Income tax ($\tau^0_{w,i}$)	0.015	0.072	0.115	0.156	0.24

Table 4: The pre-existing income tax rates are taken from the 2013 report of the Congressional Budget Office (CBO, 2013)

5.2 Revenue recycling scenarios

The purpose of this section is to describe the revenue recycling scenarios used in Section 5.3. The scenarios differ in the way the additional revenue of an environmental tax reform is returned to the households.

The tax system before the increase in the preference for environmental quality is described by the pre-existing income tax $\tau^0_{w,i}$, given by the model calibration described in Section 5.1, the pre-existing environmental tax τ^0_Z and the absence of lump-sum transfers (i.e. $L = 0$).

The increase in the preference for environmental quality leads to an increase in the optimal environmental tax level from τ^0_Z to τ_Z. The additional environmental tax revenue can be returned to the households through the following recycling mechanisms:

[13]This concept is different, however, from the concept of the *environmental* double dividend in the sense of Goulder (1995) and Bovenberg (1999): In models with only one representative household such a (weak) dividend can occur, when recycling through income tax cuts is more efficient than lump-sum recycling. A strong double dividend, that is an increase in economic efficiency, can only occur with an inefficient pre-existing tax system. In our setting, there is also an increase in GDP (see Figure 5, bottom) because the pre-existing income tax schedule creates an inefficient labor supply.

1. Non-linear income tax cuts: In this scenario the government endogenously determines the optimal income tax cut $\tau_{w,i} < 0$. Lump-sum transfers are zero, and the government's maximization problem then is

$$\max_{\tau_{w,i},\tau_Z} W \quad \text{s.t.} \quad \text{Eq. (12)} \quad \text{and} \quad G = \sum_{i=1}^{N} (\tau^0_{w,i} + \tau_{w,i})\phi_i w(T - l_i) + \tau_Z Z.$$

   The auxiliary function H in the households' first-order conditions (see Appendix A Equations 17 - 19) changes accordingly:

$$H(w, p_D, \tau^0_{w,i}, \tau_{w,i}) = ((1 - \tau^0_{w,i} - \tau_{w,i})\phi_i wT - p_D D_0).$$

2. Linear income tax cuts: The tax revenues are redistributed via linear income tax cuts. Lump-sum transfers are equal to zero and the equations are analogous to the case of non-linear income tax cuts only with $\tau_{w,i} = \tau_w < 0$.

3. Lump-sum transfers: we model household heterogeneity explicitly and uniform lump-sum transfers L to each income class are hence a realistic revenue-recycling mechanism. In this case the government maximization problem reads:

$$\max_{L,\tau_Z} W \quad \text{s.t.} \quad \text{Eq. (12)} \quad \text{and} \quad G = -NL + \sum_{i=1}^{N} \tau^0_{w,i}\phi_i w(T - l_i) + \tau_Z Z.$$

   Again, the auxiliary function H in the households' first-order conditions (see Appendix A Equations 17 - 19) changes accordingly:

$$H(w, p_D, \tau^0_{w,i}, L) = ((1 - \tau^0_{w,i})\phi_i wT + L - p_D D_0).$$

5.3 Results

In this section, we compare three environmental tax revenue recycling scenarios, in which the government has a preference for environmental quality ξ greater than zero, to the case of $\xi = 0$. Furthermore, we compare the three scenarios against each other in terms of their equity impacts and their implications for the tax system.

The main mechanism through which an environmental tax acts on the distribution remains unchanged: poor households cannot substitute clean for polluting consumption as freely as high-income households, due to our assumption of non-homothetic preferences.

The main results are: First, the Gini coefficient (see Figure 5, middle left) is strongly reduced by non-linear income tax cuts, closely followed by uniform lump-sum transfers (i.e. both recycling mechanisms lead to a double dividend of redistribution). Linear income tax cuts, by contrast, increase the Gini coefficient slightly, compared to the initial scenario. It can be seen from the top left graph of Figure 5 that rich households benefit relatively more from linear income tax cuts than poor households. The opposite is true for non-linear income tax cuts. Since rich households pay a higher total share of taxes, uniform lump-sum redistribution is also progressive. Second, the optimal environmental tax depends on the way the tax revenues are returned to the households. In the top right graph of Figure 5 we see a correlation between the progressivity of the recycling mechanism and the optimal level of the environmental tax: more progressive recycling leads to higher optimal environmental taxes. Third, we additionally obtain an environmental double dividend in the sense of Goulder (1995) and Bovenberg (1999): Setting the environmental tax at its optimal level yields revenues which are used to optimally adjust the inefficient initial income tax schedule, which increases the GDP (see Figure 5, bottom).

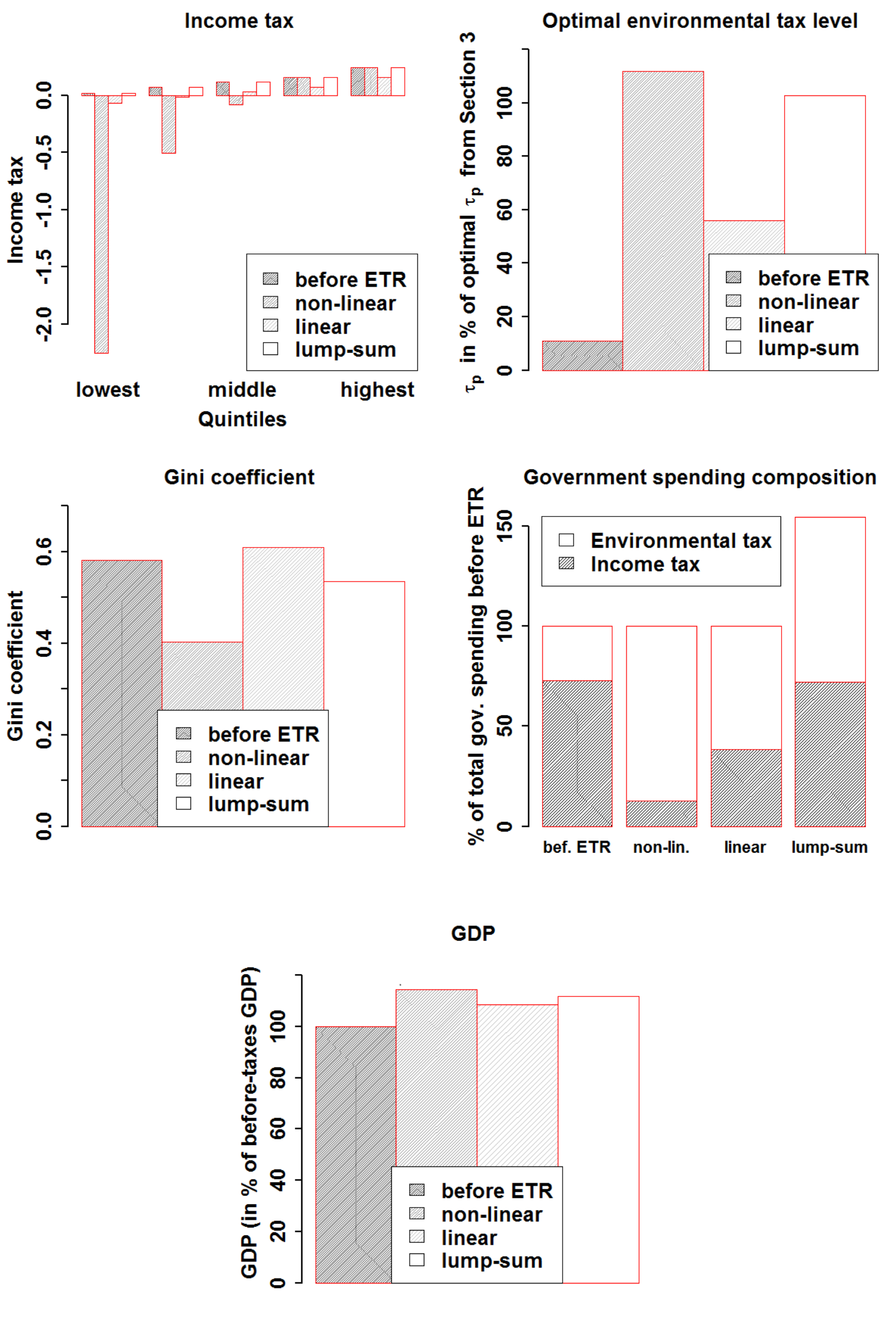

Figure 5: Effect a greening of the government's preferences for environmental quality on income taxes, optimal environmental tax levels, the Gini coefficient, the composition of government spending and GDP. The case of non-optimal pre-existing income taxes. We compare three designs of an environmental tax reform.

6 Conclusion

We analyze the effects of an optimal environmental tax reform when environmental taxation is regressive. Specifically, we quantify the distributional impacts and changes in the optimal tax structure induced by an optimal environmental tax reform. For this purpose it is necessary to combine key elements from several literature strands: Mirrleesian income taxation in the presence of an externality (as in Cremer et al. 1998 and Jacobs and De Mooij 2015), comparing different design options for environmental tax reforms (as in Kaplow 2012) and determining the distributional impacts of an environmental tax reform when accounting for price effects, outside the optimum (as in Fullerton and Heutel 2007, 2010).

An environmental tax reform has distributional impacts both on the household side and on the firm side. Assessing the distributional impacts of such a reform hence requires accounting for all these effects. Our model therefore combines a household side as in a traditional optimal taxation model with an optimizing firm side as in models that focus exclusively on price effects outside the optimum. Our study is the first to analyze the distributional effects of optimal environmental tax reforms in a setting which combines both firm-side and household-side distributional effects.

We analyze two different scenarios: first, a scenario in which the tax system before the environmental tax reform is optimal from a non-environmental point of view. Second, a scenario in which the tax system before the environmental tax reform is calibrated to U.S. data (and inequality is suboptimally high) and in which the government is constrained to different revenue recycling options. We show that, in the first scenario, the regressive effect of the environmental tax can be largely or even completely offset by the revenue recycling (depending on the available revenue recycling mechanisms). In the second scenario, we show that inequality can be reduced significantly if the environmental tax revenue is recycled either lump-sum, or through a progressive income tax reform. Furthermore, we demonstrate that more progressive recycling leads to higher optimal environmental taxes. Whenever an environmental tax reform reduces inequality a *double dividend of redistribution* occurs.

These findings have important political consequences: an environmental tax reform can reduce inequality below initial levels by simple measures such as recycling the revenue as per-capita cash transfers. Even higher distributional gains can be achieved by an environmental tax-financed (budget-neutral) progressive reform of the income tax system. However, this policy might be less feasible politically.

Possible extensions include performing a similar analysis in an intertemporal setting, accounting for structural changes in the economy, and taking the difference in factor ownership of the income quintiles into account. Furthermore, since an equitable income distribution might also be seen as a public good (Thurow, 1971), it may be worthwhile to endogenize public consumption (as in Bovenberg and van der Ploeg 1994, 1996) and to analyze possible trade-offs between these two public goods.

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A First-order conditions of households and firms

Households:
By combining the households' first-order conditions with their budget equation, the following explicit demand functions can be derived:

$$C_i = \frac{\alpha}{p_C(\alpha+\beta+\gamma)} H(w, p_D, \tau_{w,i}, L), \tag{17}$$

$$D_i = \frac{\beta}{p_D(\alpha+\beta+\gamma)} H(w, p_D, \tau_{w,i}, L) + D_0 \tag{18}$$

$$l_i = \frac{\gamma}{(\alpha+\beta+\gamma)(1-\tau_{w,i})\phi_i w} H(w, p_D, \tau_{w,i}, L), \tag{19}$$

with

$$H(w, p_D, \tau_{w,i}, L) = ((1-\tau_{w,i})\phi_i w T + L - p_D D_0). \tag{20}$$

Firms:
Maximizing profits of both firms yields four first-order conditions:

$$w = \frac{\partial F_j(T_j, Z_j)}{\partial T_j} = \varepsilon_j T_j^{(r-1)} F_j^{(1-r)} p_j, \tag{21}$$

$$\tau_Z = \frac{\partial F_C(T_C, Z_C)}{\partial Z_C} = (1-\varepsilon_j) Z_j^{(r-1)} F_j^{(1-r)} p_j, \tag{22}$$

with $j \in \{C, D\}$.

References

Ballard, C. L., Goddeeris, J. H., Kim, S. K., 2005. Non-homothetic preferences and the non-environmental effects of environmental taxes. International Tax and Public Finance 12, 115–130.

Bento, A. M., 2013. Equity Impacts of Environmental Policy. Annual Review of Resource Economics 5(1), 181–196.

Bento, A. M., Goulder, L. H., Henry, E., Jacobsen, M. R., Haefen, R. H. V., 2005. Distributional and Efficiency Impacts of Gasoline Taxes : An Econometrically Based Multi-market Study. American Economic Review 95(2), 282–287.

Berg, A., Ostry, J. D., Zettelmeyer, J., 2012. What makes growth sustained? Journal of Development Economics 98(2), 149–166.

Bovenberg, A. L., 1999. Green Tax Reforms and the Double Dividend: an Updated Reader's Guide. International Tax and Public Finance 6, 421–443.

Bovenberg, A. L., van der Ploeg, F., 1994. Environmental policy, public finance and the labour market in a second-best world. Journal of Public Economics 55(3), 349–390.

Bovenberg, A. L., van der Ploeg, F., 1996. Optimal taxation, public goods and environmental policy with involuntary unemployment. Journal of Public Economics 62, 59–83.

CBO, 2013. The Distribution of Household Income and Federal Taxes, 2010. Congress of the United States – Congressional Budget Office 4613 (December).

Chiroleu-Assouline, M., Fodha, M., 2014. From regressive pollution taxes to progressive environmental tax reforms. European Economic Review 69, 126–142.

Combet, E., Ghersi, F., Hourcade, J.-C., Théry, D., 2010. Carbon Tax and Equity The importance of Policy Design. In: Dias Soares, C., Milne, J., Ashiabor, H., Deketelaere, K. (Eds.), Critical Issues in Environmental Taxation vol. VIII, pp. 277–295, Oxford University Press, Oxford.

Copeland, B. R., Taylor, M. S., 1994. North-South Trade and the Environment. The Quarterly Journal of Economics 109(3), 755–787.

Cremer, H., Gahvari, F., 2001. Second-best taxation of emissions and polluting goods. Journal of Public Economics 80, 169–197.

Cremer, H., Gahvari, F., Ladoux, N., 1998. Externalities and optimal taxation. Journal of Public Economics 70, 343–364.

DeNavas-Walt, C., Proctor, B. D., Smith, J. C., 2012. Income, Poverty, and Health Insurance Coverage in the United States: 2011. U.S. Census Bureau, Current Population Reports pp. 60–243.

Dissou, Y., Siddiqui, M. S., 2014. Can carbon taxes be progressive? Energy Economics 42, 88–100.

Ekins, P., 1999. European environmental taxes and charges: recent experience, issues and trends. Ecological Economics 31, 39–62.

Engel, E., 1857. Die Productions-und Consumtionsverhältnisse des Königreichs Sachsen. Zeitschrift des sächsischen Statistischen Bureaus des Innern 8 and 9, 1–54.

Flues, F., Thomas, A., 2015. The Distributional Effects of Energy Taxes: Preliminary Report. OECD Taxation Working Papers (23).

Fullerton, D., Heutel, G., 2007. The general equilibrium incidence of environmental taxes. Journal of Public Economics 91, 571–591.

Fullerton, D., Heutel, G., 2010. Analytical General Equilibrium Effects of Energy Policy on Output and Factor Prices. The B.E. Journal of Economic Analysis & Policy 10(2), 1–24.

Fullerton, D., Hong, I., Metcalf, G. E., 2001. A Tax on Output of the Polluting Industry is not a Tax on Pollution. The Importance of Hitting the Target. In: Carraro, C., Metcalf, G. E. (Eds.), Behavioral and Distributional Effects of Environmental Policy, pp. 13–44, University of Chicago Press.

Fullerton, D., Metcalf, G. E., 2001. Environmental controls, scarcity rents, and pre-existing distortions. Journal of Public Economics 80, 249–267.

Fullerton, D., Monti, H., 2013. Can pollution tax rebates protect low-wage earners? Journal of Environmental Economics and Management 66(3), 539–553.

Goulder, L. H., 1995. Environmental taxation and the double dividend: A reader's guide. International Tax and Public Finance 2(2), 157–183.

Goulder, L. H., Parry, I. W., Williams III, R. C., Burtraw, D., 1999. The cost-effectiveness of alternative instruments for environmental protection in a second-best setting. Journal of Public Economics 72, 329–360.

Grainger, C. A., Kolstad, C. D., 2010. Who Pays a Price on Carbon? Environmental and Resource Economics 46(3), 359–376.

Jacobs, B., De Mooij, R. A., 2015. Pigou meets Mirrlees: On the irrelevance of tax distortions for the second-best Pigouvian tax. Journal of Environmental Economics and Management 71, 90–108.

Jacobs, B., van der Ploeg, F., 2010. Precautionary climate change policies and optimal redistribution. OxCarre Research Paper 49.

Kaplow, L., 2004. On the (ir)relevance of distribution and labor supply distortion to government policy. The Journal of Economic Perspectives 18(4), 159–175.

Kaplow, L., 2012. Optimal control of externalities in the presence of income taxation. International Economic Review 53(2), 487–509.

Klenert, D., Mattauch, L., 2016. How to make a carbon tax reform progressive: The role of subsistence consumption. Economics Letters 138, 100–103.

Kumhof, M., Rancière, R., Winant, P., 2015. Inequality, leverage, and crises. American Economic Review 105(3), 1217–45.

Levinson, A., O'Brien, J., 2015. Environmental Engel Curves. NBER Working Paper Series 20914.

Ligthart, J. E., van der Ploeg, F., 1999. Environmental Policy , Public Goods and the Marginal Cost of Public Funds. Environmental and Resource Economics 13, 187–207.

Marrero, G. A., Rodríguez, J. G., 2013. Inequality of opportunity and growth. Journal of Development Economics 104, 107–122.

Mirrlees, J., 1971. An Exploration in the Theory of Optimum Income Taxation. The Review of Economic Studies 38(2), 175–208.

OECD, 2011. Divided we stand: Why inequality keeps rising. OECD Publishing .

Piketty, T., 2014. Capital in the twenty-first century. Harvard University Press.

Rosenthal, R. E., 2014. GAMS A User's Guide. GAMS Development Corporation, Washington, DC, USA .

Sandmo, A., 1975. Optimal Taxation in the Presence of Externalities. The Swedish Journal of Economics 77(1), 86–98.

Sterner, T., 2011. Fuel Taxes and the Poor: The Distributional Effects of Gasoline Taxation and Their Implications for Climate Policy. RFF Press, New York.

Thurow, L. C., 1971. The Income Distribution as a Pure Public Good. The Quarterly Journal of Economics 85(2), 327–336.

Wier, M., Birr-Pedersen, K., Jacobsen, H. K., Klok, J., 2005. Are CO_2 taxes regressive? Evidence from the Danish experience. Ecological Economics 52(2), 239–251.

Chapter 4

The fiscal benefits of climate policy: an overview[1]

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[1]Based on Siegmeier, J., Mattauch, L., Franks, M., Klenert, D., Schultes, A., and Edenhofer, O., 2016. The fiscal benefits of climate policy: an overview. In preparation for submission to *CESifo Economic Studies*. A previous version is available as a FEEM Working Paper: Siegmeier, J., Mattauch, L., Franks, M., Klenert, D., Schultes, A., Edenhofer, O., 2015. A Public Finance Perspective on Climate Policy: Six Interactions That May Enhance Welfare. FEEM Nota di lavoro, 31.2015.

The fiscal benefits of climate policy: an overview

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Abstract

Climate change economics mostly neglects sizeable interactions of carbon pricing with other fiscal policy instruments. Conversely, public finance typically overlooks the effects of future decarbonization efforts when devising instruments for the major goals of fiscal policy. We argue that such a compartmentalisation is undesirable: policy design taking into account interdependencies may enhance welfare and change the distribution of mitigation costs within and across generations. To support this thesis, we systematically discuss the hitherto identified interactions between climate change mitigation and public finance. These concern, first, public revenue-raising, as climate policy may reduce tax competition and induce macroeconomic portfolio effects. Second, they concern public spending, which needs to be restructured in line with climate policy, while carbon pricing revenues may be recycled for productive public investment. Finally, distributional effects matter, since intragenerational equity depends on appropriate revenue recycling and intergenerational Pareto-improvements are possible through intertemporal transfers. We thus show that jointly considering carbon pricing and fiscal policy is legitimate and mandatory for sound policy appraisal.

JEL classification: B41, H21, H23, H54, H60, Q54

Keywords: Carbon pricing, taxation, public spending, redistribution, policy interactions

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1 Introduction

Climate economics usually considers only inefficiencies directly related to climate change mitigation. It typically ignores interactions with other fiscal policy instruments, such as taxes, subsidies or public investment that are motivated by non-climate aims such as job creation, debt reduction, provision of infrastructure, health services, education or distributive justice. Vice versa, public finance typically ignores constraints and opportunities of future decarbonization when designing instruments for such major goals of fiscal policy.

However, some instruments of climate policy would generate large revenue streams. Assume for a crude approximation that a carbon price of US$15 per ton of CO_2 was applied to 6 billion tons of CO_2 emitted by the United States in 2005: This amounts to annual revenues of US$90 billion, ignoring behavioral responses (Metcalf (2007); for more elaborate estimations, see Bauer et al. (2013), or Carbone et al. (2013)). Given revenues of this magnitude and their distributional significance, interactions between climate policy and other fiscal policy instruments are non-negligible. These interactions also depend on the way these revenues are spent, and the distortions and scarcity rents created or affected by climate policy. Ignoring such interactions in climate economics may lead to inaccurate policy appraisal in two ways: first, the situation prior to a policy reform is inaccurately described because some important distortions are neglected; second, taking into account these distortions will attribute greater welfare gains to policy reform. Along similar lines, for public finance, taking the challenge of climate change mitigation into account may offer new solutions to well-known problems.

This article argues that standard welfare analysis of both climate change mitigation policy as well as fiscal policy neglect important interactions between the two that (1) lead to efficiency gains and (2) impact intra- and intergenerational distribution. To support this thesis, we discuss and structure the hitherto identified interactions between climate change mitigation and public finance, which can be grouped under the topics of public revenue-raising, public spending and distribution. Each effect is attributable to a coincidence of the climate externality with a second major externality or goal of public finance. Whenever such effects occur, taking them into account by an integrated design of fiscal- and climate policies may lead to welfare gains that would be forgone by separate treatment of the public finance topics and climate mitigation.

In contrast to well-known 'double dividend' arguments of environmental taxation, all arguments but one are independent of the assumption of preexisting inefficient taxes and most of the effects analyzed are unambiguously welfare-enhancing. We both summarize mechanisms that have already been described in the existing (if sparse) literature on public finance topics in climate policy (but were largely omitted in previous overviews on the fiscal dimension of climate policy, such as Jones et al. (2012) or de Mooij et al. (2012)), and discuss some previously unexamined effects. We conclude by discussing why it is methodologically legitimate to integrate climate change mitigation policies into public finance and outline potential implications for policy assessment.

We briefly review the standard approach of climate economics as well as the argument that an environmental tax swap may offer a double-dividend (Section 2). In the main part (Section 3), we first consider other effects related to the raising of public revenues via climate policy instruments. There are two effects, one in an open economy, the other in a closed economy, and both related to capital accumulation:

1. There are sizable welfare losses from international capital tax competition. These can be shown to be mitigated when climate policy revenues replace capital taxation in an open economy where capital is mobile (Section 3.1).

2. Climate policy inevitably creates new rents. If private capital is insufficiently accumulated, rent collection causes distortions that are beneficial (besides correcting the climate externality and collecting the rents for distributional motives). These distortions increase aggregate efficiency by redirecting investment towards producible capital (Section 3.2).

We then consider the structure and the total level of public expenditures:

3. The provision of different combinations of public investment (at a given total level) affects both the direct costs of climate change mitigation and the strength of its general equilibrium effects. The degree to which direct climate policy is matched by a restructuring of public goods provision thus affects future productivity and macroeconomic efficiency (Section 3.3).

4. When government funding from other sources is lower than optimal, it can be beneficial that some climate policy instruments raise additional funds. We consider spending options with a positive aggregate effect, such as investment in underfinanced public capital stocks or public debt reduction (Section 3.4).

Finally, we consider issues of intra- and intergenerational (re)distribution due to climate policy:

5. If inequality (at a point in time) impairs economic performance, or if equality as such is considered to be a component of social welfare, there are welfare losses from high inequality. While the direct effect of climate policy on heterogeneous households is likely to be regressive, revenues from climate policy instruments can be used to more than offset this regressivity. This may be achieved by tax rebates for low-income households or public spending on education and local public goods (Section 3.5).

6. There are large intergenerational gains from using public finance instruments to redistribute the costs and benefits of climate change mitigation over time: If climate policy were combined with intergenerational redistribution so that future generations contribute to mitigation efforts, the net mitigation costs could be negative at each point in time, implying a Pareto-improvement across generations (relative to the no-policy case). Options for organizing such a transfer include changes to debt policy and to pension schemes (Section 3.6).

These arguments are based on the premise that climate policy and additional non-climate effects should not be studied separately, but within a comprehensive public finance framework. The reason is that separate estimates cannot be directly added up due to the non-negligible general equilibrium effects that effective mitigation policies would cause. Our discussion addresses this as well as potential consequences for the evaluation of climate change mitigation policies, both in climate economics and public economics (Section 4).

2 Current assessments of climate change mitigation policies

This section summarizes two strands of literature on which our study builds: First, mitigation strategies have commonly been evaluated by so-called integrated assessment models. Our brief description of the main methods in Section 2.1 underlines the contrast between highly detailed modeling of climate change, its damages and technological mitigation strategies, and the simplified treatment of the policy space, which is confined to climate policy. Second, Section 2.2 covers the 'double dividend' debate as the most prominent attempt to include interaction effects of carbon taxes with fiscal policy.

2.1 Integrated assessment modeling of optimal mitigation and second-best policies

Optimal climate change mitigation targets, pathways to implement them and the associated gross and net mitigation costs (without and with avoided damages from climate change) are commonly estimated with integrated assessment models (IAMs). These are numerical simulations that combine a model of the climate system with an economic model (typically a multi-sector neoclassical growth model). Two optimization approaches[1] can be distinguished by their treatment of mitigation targets and damages due to climate change: cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA).

CBA in the context of climate change focuses on the optimal choice of a mitigation target, which is determined by weighing the opportunity costs of consumption foregone by investing into mitigation against the benefits of avoided damages from climate change, expressed as social costs of carbon, which are the economic damages resulting from a marginal increase in carbon emissions (the difference between costs and benefits gives the net costs, which are negative for the optimal mitigation path). In principle, this requires a detailed representation of a multitude of channels by which climate change may affect human welfare, such as a rising sea level, extreme weather events (for example storms, heat waves, droughts), water availability, the spread of diseases or agricultural yields (Reilly et al., 2013). Instead, stylized damage functions are standardly used to capture some of these effects (e.g. Hope (2006), Nordhaus (2007)).[2] Thus, findings of different IAMs used for CBA depend on their respective modeling of market- and non-market damages, as well as the choice of the social discount rate, treatment of uncertainty and extreme outcomes, or

[1]Alternatively to optimization with policy variables as controls, the effects of a given policy proposal can be simulated with IAMs to evaluate its costs. This is called the evaluation approach (Weyant et al., 1996).

[2]A rare exception is Reilly et al. (2013), who explicitly model the health effect of higher ozone concentrations due to climate change.

substitution possibilities between physical capital and environmental services (Stern, 2007; Ackerman et al., 2009; Weitzman, 2009; Pindyck, 2013).

CEA focuses on optimal strategies to achieve an exogenously given mitigation target (damage level). Only mitigation measures and gross policy costs, for instance, expressed as discounted consumption losses, are determined endogenously. Thus, the complexity of modeling climate damages is avoided; instead, high-emission sectors and mitigation technologies are represented in more detail. This also allows for a comparison of different assumptions about the availability of technologies to inform policy choices: for example, the 'option value' of developing carbon-capture-and-storage or nuclear power for decarbonisation can be estimated (see for example Luderer et al. (2012), or Clarke et al. (2014) for an overview).

Thus, the representation of the climate system and emission-relevant economic sectors is often highly detailed in IAMs of either type - but other welfare-relevant aspects of the socio-economic system that have strong interactions with climate change and mitigation strategies, such as health or the distribution of income and wealth, are often only modeled in a crude and incomplete fashion, or not at all: For example, health is only considered in terms of negative effects of climate change, and mostly only as part of the motivation for very stylized aggregate damage functions. The distributions of income and wealth within countries are generally not considered.[3]

A more detailed representation of these non-climate aspects of welfare and related inefficiencies is important for both the identification of optimal mitigation strategies, and for the analysis of specific policies: First, the optimal mitigation paths and the related costs and welfare effects obtained from IAMs may change, since (1) there may be trade-offs (in a CBA) between investing in the low-carbon transition or for example poverty reduction (Dasgupta, 2007), and (2) some non-climate objectives, such as health or distribution, are strongly affected not only by climate change itself, but also by the choice of mitigation measures (examples: local air pollution from electricity generation and transport, health effects of non-motorized transport, food prices affected by biofuel demand). Ignoring non-climate inefficiencies may lead to a too optimistic description of the situation without climate change mitigation, and ignoring the interactions with mitigation measures leaves out important welfare gains that can be attributed to it. For this study, this means that the welfare gains described occur relative to a baseline that contains more inefficiencies than standardly considered by IAMs.

Second, it is even more important to take into account non-climate issues when practical GHG mitigation policies are considered in decentralized models, because limitations of climate- and non-climate policy instruments imply even more scope for interactions. It is common practice to analyze climate policy instruments (such as different forms of carbon pricing, emission standards or R&D support schemes for low-carbon technology) in second-best settings with another non-climate inefficiency, but the latter is usually directly related to emission-relevant sectors (such as imperfect coverage of carbon pricing schemes, or market failures in the energy sector related to innovation or

[3]This refers to models for determining globally optimal GHG mitigation pathways. For related literature that does include distributional and health effects see, for example, Rausch et al. (2010) who analyze specific climate policy instruments for the USA with respect to their distributional effects; Thompson et al. (2014) additionally include health effects.

imperfect competition). In such settings, it is generally preferable to use more than one policy instrument to address all sources of market failure, and to adjust these instruments to each other (e.g. Sorrell and Sijm (2003), Fischer and Newell (2008), Gillingham et al. (2009), Fischer and Preonas (2010), Kalkuhl et al. (2011), Kalkuhl et al. (2013), Mattauch et al. (2015); Aldy et al. (2010) provide a good overview).

We argue that second-best analysis of climate policy should be systematically extended to include inefficiencies (and policies to correct them) that are neither related to climate change nor specific to emission-relevant sectors, but nevertheless have interactions with mitigation policies. Integrating them is important for the choice, design and evaluation of policy reform packages that involve both climate- and non-climate policies (see also Section 4).

2.2 Lower cost of public funds: The 'double dividend' of environmental tax swaps

There is one interaction of environmental and fiscal policies that has been discussed very prominently: the use of pollution tax revenues for cutting distortionary taxes elsewhere and potentially reaping a 'double dividend' (Tullock (1967); see Pearce (1991) for an early application to climate policy). We summarize the argument because it is structurally similar to those brought up in the next section, and because this similarity makes clear how policy-relevant these new effects are, given the considerable political impact of the 'classical' double dividend argument.

Assume some unspecified public spending requirement in a second-best setting where no lump-sum taxes but only distortionary taxes are available (this is the additional non-environmental inefficiency here), so the costs of raising public funds are non-zero. Then, if an environmental policy is introduced that not only corrects an externality (the first dividend), but also generates revenues, this could lower the cost of public funds (the second dividend) and thus the gross costs of environmental policy, because distortionary taxes could be reduced ('revenue recycling effect'). The claim that this constitutes an improvement over lump-sum recycling of the revenues to households is called the 'weak' double dividend hypothesis, which is widely confirmed to hold (Goulder, 1995b; Bovenberg, 1999).[4]

More controversial is a stronger version of the hypothesis: an environmental tax swap does not only have lower, but even zero or negative gross costs. However, via general equilibrium effects, environmental taxes can also exacerbate the distortions from pre-existing taxes in factor markets that they are meant to reduce: Higher product prices reduce real factor returns, thus substituting an implicit for an explicit tax and causing a negative third effect on welfare, the so-called 'tax interaction effect' (Bovenberg and De Mooij, 1994; Bovenberg and van der Ploeg, 1994; Parry, 1995). Due to the narrower tax base, this may more than offset the revenue recycling effect, thus increasing the gross costs and rendering a strong double dividend unlikely (the net costs including benefits from higher environmental quality are likely to remain negative).

[4]Another case of a 'double dividend' is the so-called employment dividend, where an environmental tax reduces involuntary employment (Carraro et al., 1996; Bovenberg, 1999).

For the case of a carbon tax, early numerical simulations supported these findings (Goulder (1995a,b); see also the review by Bosello et al. (2001)).

However, some crucial assumptions of the original analysis have been challenged. We summarize three arguments that make the existence of a second, fiscal dividend of climate policy more likely:

First, the strong double dividend hypothesis is more likely to hold if the initial tax system is inefficient, and if the environmental tax swap moves it closer to its non-environmental optimum. As summarized by Bovenberg (1999) and Goulder (2013), this includes situations when clean goods are better substitutes for leisure than dirty goods, but consumption is uniformly taxed; when taxation imposes different marginal excess burdens on different factors; when polluting activities are initially subsidized; when the environmental tax (partially) falls on Ricardian rents from a fixed factor used in the production of polluting goods (Bento and Jacobsen, 2007); or when labor markets are imperfect (Koskela et al., 1998; Koskela and Schöb, 2002; Schöb, 2005). A related effect is the potential reduction of the informal sector (and broadening of the labor tax base) that may result from an environmental tax swap (Markandya et al., 2013).

Second, the studies above rejecting the strong double dividend hypothesis mostly rest on the assumption that environmental quality enters the utility function only, where it is (weakly) separable from consumption and leisure. This separability assumption has been challenged, either because environmental damages may shift consumption towards 'defensive expenditures' (Schöb, 1995; FitzRoy, 1996), or because improved environmental quality implies better health and thus potentially higher labor supply (Schwartz and Repetto (2000); substantial positive health co-benefits of climate policy due to local air quality improvements have been found e.g. by Thompson et al. (2014)). Each works in favor of a strong double dividend. A counter-effect is that improved environmental quality may also act as a complement to leisure, thus reducing labor supply (Bovenberg and van der Ploeg, 1994).

Third, and maybe most importantly, it is unclear if environmental quality interpreted as the long-run climate is adequately modeled as a direct impact on utility only. If it is assumed on the contrary that environmental quality also serves as a public input to production, as is common in much of climate change economics (for examples, see Nordhaus (1993) or Tol and Fankhauser (1998)), a strong double-dividend also becomes more likely (Bovenberg and de Mooij, 1997).[5] Barrage (2014) finds that neglecting climate change impacts on production and only focusing on direct utility losses leads to a carbon tax that is around 10% lower than optimal.

Overall, this underlines the importance of designing and analyzing climate policy in conjunction with the tax system due to fiscal interactions (Goulder, 2013). But despite being in the focus of previous literature on interactions between environmental and other public economics, a distortionary tax system is by far not the only additional non-climate source of inefficiency, and its revenue-neutral restructuring not the only policy option that needs to be

[5]Goulder (1995b, p.169) notes that when environmental quality is an input to production, the notion of 'gross costs' of tax reform as welfare costs without direct environmental benefits becomes ambiguous: "*In my view, [the result of Bovenberg and De Mooij (1994)], strictly speaking, does not provide support for the strong double-dividend notion because it involves benefit-side issues; this is not a case of negative gross costs.*"

considered in a full assessment of the costs of climate policy. We now turn to additional effects that have been underappreciated so far.

3 Why climate change mitigation enhances welfare

In this section we give an overview of specific arguments for the thesis that interactions of climate change mitigation with other public policy objectives enhance welfare beyond the environmental improvement.

We first consider the advantages of a tax on carbon emissions for raising public revenues, both in an open economy subject to tax competition under capital mobility (Section 3.1) and in a closed economy when it affects investment behavior (Section 3.2).

Two further arguments concern public expenditures: the effect of restructured public spending on private abatement costs or general equilibrium effects (Section 3.3), and options to spend additional revenue from climate policy on productive public capital or for debt reduction (Section 3.4).

The final two arguments concern the intra- and intergenerational distribution of the costs of climate change: At any point in time, a carbon tax is likely to be regressive. However, its revenues may be so high that not only compensating measures could be financed, but even inequality reductions beyond that (Section 3.5). Over time, it might be possible to reallocate some of the future benefits of avoided climate damages to reduce current mitigation costs. When combined with such a transfer the correction of the climate externality should not lead to net costs to any generation (Section 3.6). These distributive consequences of climate policy matter normatively, but also crucially affect political feasibility, which is a topic we only elaborate on briefly in this review.

Of course, this list is not exhaustive; the focus of this article is to point out in a structured manner when welfare impacts of climate policy have been underexplored, not to exhaustively review the field. Other non-climate inefficiencies which may interact with climate policy include informational asymmetries between the government and the private sector, horizontal and vertical externalities of public policies in countries with a federal structure (Keen, 1998), labor market rigidities (Guivarch et al., 2011), tax-base effects related to the informal economy (Markandya et al., 2013), or weak institutions leading to tax evasion (Liu, 2013). Cyclical climate policy or ‘Green Keynesianism’ is another related field not considered here (Fischer and Heutel, 2013; Harris, 2013). Furthermore, not every effect will be relevant in every situation. To facilitate the selection of the most important effects for a specific policy package and economic environment, we emphasize the conditions under which each effect occurs.

3.1 Reduced international tax competition: Substituting rent taxation for capital taxation

The double dividend literature discusses a restructuring of the tax system in a closed economy. We now turn to another possibility for tax reform which is peculiar to the case of an open economy. If we assume that capital is internationally mobile,[6] social welfare could be increased if the following effect is taken into account:

When governments use climate policy revenues to finance their budgets and in turn cut taxes on private capital, this improves the efficiency of the national tax system by reducing the interregional externality of tax competition, which is due to capital mobility.

This effect may arise when three premises regarding international capital flows hold. In the field of public economics, in particular the literature on horizontal fiscal federalism, a consensus has emerged that all these premises in fact hold true. The first is that capital is mobile internationally to a sufficiently high degree (Zodrow, 2010). Second, this capital mobility restricts fiscal policy choices and causes a race-to-the-bottom in capital tax rates. Finally, this in turn leads to an inefficient underprovision of local public goods. The mechanism has been shown analytically by Wilson (1986) and Zodrow and Mieszkowski (1986). Empirically, the underprovision of local public goods is reflected e.g. in the observed underprovision of public infrastructure (Bom and Ligthart (2014); see also Section 3.3). Next to the more empirical survey by Zodrow (2010), other good overviews of the tax competition literature can be found in Wilson (1999) or Keen and Konrad (2013).

Thus, as long as capital markets are characterized by deep international integration, capital must be considered an inefficient tax base. In this international setting, taxation of fossil resources is preferable to capital taxation for three related reasons (Franks et al., 2015):

First, the supply of fossil resources is less elastic than the supply of capital, because the total stock of fossils is fixed, income from selling fossils is a rent and the resource owner will sell even at low prices, depending on buyers' behavior. Taking into account strategic behavior, it indeed turns out to be optimal to levy taxes on the use of fossil fuels and thus capture part of the resource rent.

Second, reductions of the rate of return on capital by a carbon taxes are smaller than for a capital tax. Since mobile capital chases the highest rate of return, a unilateral increase of the capital tax leads to capital flight. When instead a carbon tax is increased, then less fossil resources are used in the country. Fossil resources and capital are complementary to a certain degree, thus the return to capital also decreases. However, this indirect effect on the rate of return is weaker than the direct effect caused by capital taxation. Thus, there is relatively little relocation of capital to other countries when carbon taxes are increased unilaterally. More capital relocates under a comparable unilateral increase of capital tax rates.

Third, if revenues from fossil resource taxation finance a budget that contains productivity-enhancing public spending, e.g. on public infrastructure, this has a positive impact on rates of return to capital.

The efficiency result, that is, that carbon taxes are preferable to capital taxes, holds quite generally. Franks et al. (2015) exemplify this in a model of a global economy in which several regions compete for mobile capital and have to import fossil resources from an exporting region. They discuss two

[6] In the context of the analysis of open economies and climate policy the field of carbon leakage has received great attention. In the present study we do not discuss carbon leakage, because the overlaps between climate change economics and public finance seem less important for this topic.

assumptions about the strategic behavior of the governments of the importing and exporting countries explicitly. First, the efficiency result holds irrespective of whether the resource importing countries cooperate among each other or not. Further, it does not matter whether the resource exporting countries can coordinate their actions to influence the resource price or not.

Concerning the first assumption, a buyers' cartel may exercise a kind of monopsony power to extract the resource rent (see e.g. Tahvonen (1995); or Karp (1984)). We shall refer to this as the monopsony effect. It also occurs in the model of Franks et al. (2015). Moreover, they show how in the absence of cooperation among buyers, unilateral climate policy in the form of carbon pricing allows governments to appropriate part of the rent. Governmental expenditures enhance productivity, as shown e.g. by Bom and Ligthart (2014). Thus, as long as the effect of diminishing returns to scale does not dominate, it is optimal both from a global welfare perspective as well as from an individual country's perspective to unilaterally increase taxes. The productivity-enhancing properties of public spending align the incentives of competing resource-importing countries in a similar way as cooperation would do, such that a weak form of the monopsony effect may take place.

Second, when the governments of resource-exporting countries are assumed to interact strategically on the resource market, they will react to buyers' carbon taxation by increasing their taxes on resource exports with the effect of raising the consumer price of fossil resources. In that case, the rent that buyers may capture using the carbon tax is decreased. Nevertheless, the governments of importing countries may still capture a sufficiently large amount of the rent such that the carbon tax is superior to the capital tax.

Considering the environmental effects, Franks et al. (2015) find that an increase in both the buyers' and the sellers' taxes increases the consumer price and thus decreases the amount of resources sold. A green paradox, as brought up by Sinn (2008), does not occur. Resource sellers increase neither their rate of extraction nor the cumulative amount of extraction. Thus, substituting carbon taxes for capital taxes has beneficial environmental implications under all assumptions about strategic behavior mentioned above.

In sum, it is likely that for a wide range of assumptions about the strategic behavior of resource-buying and selling countries the unilateral substitution of carbon taxation for capital taxation increases social welfare. Through the above outlined mechanisms, such a substitution is not only attractive for countries with a strong preference for environmental protection; more importantly, it is highly relevant for countries which are exposed to the negative impacts of capital mobility and which are thus constrained by tight budgets (see also Section 3.4).

The study by Franks et al. (2015) implies that environmental and fiscal externalities such as tax competition should be studied within one integrated framework. Omitting the beneficial effects of a carbon tax on the problem of local public goods provision overstates the costs of climate change mitigation. If there is a pre-existing inefficiency, which is caused by capital tax competition, then unilaterally implementing a carbon tax enables governments to reap a double dividend of addressing climate change and alleviating tax competition.

3.2 Alleviated underinvestment: Inducing a 'macroeconomic portfolio effect' by rent taxation

The arguments above considered cuts of non-environmental taxes in return for imposing a carbon price. This section considers an effect related to investment behavior under a carbon price, independent of the rest of the tax system.

We argue here that the welfare effect of climate policy may exceed its environmental benefits if a carbon price on a flow of GHG emissions (or fossil fuel inputs) reduces the rent of an underlying stock that is part of a larger asset portfolio, and if the resulting rebalancing of this portfolio cures a non-climate inefficiency. Our example for such an inefficiency is the underaccumulation of producible capital due to imperfect intergenerational altruism.

The common argument in favor of a tax on rents – that it is non-distortionary - does not hold if there are alternative assets Feldstein (1977), since saving behavior and thus portfolio composition change. However, it has been shown that this may actually constitute an efficiency and welfare improvement, e.g. for a tax on a fixed factor, 'land', when some type of producible capital is underaccumulated (Petrucci, 2006; Koethenbuerger and Poutvaara, 2009; Edenhofer et al., 2015b). A similar effect occurs for the case of carbon pricing acting as a tax on rents from fossil fuel stocks (Siegmeier et al., 2015):

Assume that there is a finite stock of fossil resources which is fully owned, and that the extraction cost path is fixed, abstracting from new discoveries and uncertain technology improvements.

Then, without climate policy, the productive sector borrows physical capital and buys fossil fuel as input factors, while GHG emissions are free (but deplete the atmospheric reservoir). Capital yields interest payments and resource ownership yields the value of the extracted part of the stock, at a price reflecting extraction costs, the opportunity costs of extracting and selling the fuel later, and a scarcity rent (depending on demand elasticity, total supply and market structure). Households will divide their savings between capital and (ownership claims to) resources, balancing their portfolio according to a no-arbitrage condition on expected returns.

Now introduce climate policy in the form of a quantity instrument, specifically a permit scheme that directly controls the path of GHG emissions. For simplicity, assume that the government implements an upstream policy by perpetually issuing resource extraction permits, the total amount of which is exogenously given (e.g. reflecting an optimal mitigation pathway derived from an IAM, see Section 2.1). The fraction of the total resource stock that a household owns will also be the fraction of total extraction permits that this household obtains in each period.[7] Thus, households do not choose resource ownership and resource extraction independently, but the former implies the latter. Now, if the government decides to auction some or all of the permits instead of allocating them for free (or equivalently, to tax the revenues from permitted resource extraction), the resource stock owners' rent is transferred to the government. The expected returns and thus the value of the resource stock decrease, and households will direct more of their savings towards capital as the alternative asset until the no-arbitrage condition is restored due to the falling interest rate. If capital was initially underaccumulated, efficiency increases,

[7]For simplicity, we assume that the structure of the portfolio of resource stocks (which may differ for example in terms of extraction costs) is identical across homogenous households.

and the welfare losses of climate change mitigation are reduced. (Siegmeier et al., 2015) provide a formal proof for this 'macroeconomic portfolio effect' in an overlapping-generations model with an exhaustible resource and publicly financed technological progress.

The argument also applies to implementations of climate policy via a carbon tax. However, a complicating factor in this case is that mitigation can only be enforced via a tax rate that decreases over time to provide an incentive for conservation (Sinclair, 1992). Thus, the objectives of climate change mitigation and rent extraction for the public have to be weighed against each other. In contrast, a permit scheme has two policy parameters to optimally achieve both objectives: the quantity of permits and the share that is auctioned.

In practice, the most important limitations will be that the permit scheme does not cover all global resource stocks, and that ownership claims to these stocks may not be freely tradable (as required for optimal portfolio adjustment). The latter concern may be addressed by implementing climate policy as a scheme of individual ownership claims to the stock of the atmosphere, which might change the political economy of climate policy (Siegmeier et al., 2015).

So far, we have neglected uncertainty, which is of central importance in the resource sector: The costs of exploration and extraction and research efforts to lower them, total supply of fossil fuels, and the costs of substitute technologies are generally highly uncertain. While the portfolio effect described above will still occur under uncertainty, additional effects are possible - among them a 'second-order' portfolio effect may arise between equally risky investment opportunities: If climate policy extracts rents from the fossil resource sector, the attractiveness of investment into resource exploration endeavors or R&D in extraction technologies deteriorates vis-à-vis R&D in resource productivity or substitutes for fossil fuels, for example renewable sources of energy.[8] Lower investment in risky fossil resource projects is likely to increase extraction costs and decrease resource supply in the future, thus providing an additional incentive for improving resource productivity and reducing the costs of renewables.

Relaxing other simplifying assumptions such as ideal policy implementation and market structures may also affect the importance of the macroeconomic portfolio effect for the relative efficiency of specific carbon pricing schemes - but not its general occurrence whenever fossil resource stocks are one of several investment options.

3.3 Lower private abatement costs: Restructuring public spending

We now turn to public spending: This subsection discusses the implications of climate policy for the optimal composition of public spending; the next subsection considers its optimal level.

Our argument here is that the structure of public spending is insufficiently adjusted to policies that directly target GHG emissions, and vice versa. Efficient and effective climate policy consists of two parts: Direct measures (such as a carbon price) to induce private substitution of clean for dirty technologies,

[8]Although the funds withdrawn from such fossil resource projects could also be directed towards less risky assets altogether, it is plausible that some investors ('venture capitalists') will switch to risky alternatives, including R&D in renewable energy technologies which at the same time become more attractive under a credible political commitment to climate protection.

and indirect, complementary adjustments of public spending (in particular on physical infrastructure) so that private abatement is less costly, because the utility and/or productivity of clean substitutes are enhanced. These two parts are typically not optimized together, although doing so would significantly lower total costs of climate policy and increase social welfare.

We highlight the importance of public spending for climate change mitigation, point out how this fact is neglected in mainstream analysis and practical implementations of climate policy, and summarize first insights and future challenges regarding the integration of direct and indirect climate policy.

The feasibility and costs of climate change mitigation depend on how fast different parts of the capital stock can be adapted to the use of low-carbon technologies, since almost 80% of today's emissions are directly related to producible capital, as they stem from burning fossil fuels and industrial processes (IPCC, 2014). Emissions are reduced by clean substitution of directly GHG-emitting devices such as power plants or vehicles, but the speed and costs at which this can be done also strongly depend on the (non-emitting) physical systems that complement them,[9] such as the wider electricity system and transport infrastructure. These parts of the capital stock are often publicly financed or subsidized, and differ strongly between high- and low-emission scenarios, so the structure of public spending plays a key role for the low-carbon transition.

This can be illustrated by contrasting two studies: Davis et al. (2010) calculate emissions 'committed' by already existing directly CO_2-emitting capital stocks, and find that using these devices to the end of their technical lifetimes (up to 40 years) could lead to a global warming of 1.3 °C by 2060. They acknowledge the role of non-emitting parts of the existing capital stock for the inertia of the system, but do not model them. Guivarch and Hallegatte (2011) partly close this gap by additionally modeling transport infrastructure and asset location, which cause inertia in transport demand. They show that this implies committed emissions that are 35% higher in 2030 than those projected by Davis et al. (2010). Furthermore, they find that if this additional inertia as well as non-carbon GHG are accounted for, a 2 °C warming target cannot be achieved by only regulating new investments (as could be erroneously concluded from Davis et al. (2010)). Instead, even existing capital stocks need to be adjusted by retrofitting or premature retirement, including "*the drivers of energy services demand, and in particular modal shift and mobility needs linked to infrastructure and assets locations*" (Guivarch and Hallegatte, 2011, p.804). Similar results could be expected from extensions for other high-emission sectors, in particular energy, where non-emitting capital stocks such as networks for electricity and gas transport or sea ports for coal and liquefied natural gas play a large role, for supply as well as demand.[10]

[9]The "carbon lock-in" literature discusses a wide range of sources of inertia in GHG-emitting activities, which may be interdependent in a "techno-institutional complex" (Unruh, 2000). We focus here on technological dependencies only.

[10]While infrastructure in the transport sector is still largely publicly owned, privatization in the energy sector has often included infrastructure such as electricity and gas networks, backup generation capacity, or gas storage. But since the energy sector for technological reasons suffers from a host of market failures, it remains heavily regulated: Prices and important physical infrastructure parameters (e.g. location, type and size of installations) are still generally controlled by government agencies, and subsidies are significant. Thus, even though changing the energy infrastructure may not be a pure public spending issue, it is still a subject of public policy

Despite its central role for decarbonisation, infrastructure spending has been neglected in the analysis, design and implementations of optimal mitigation pathways and climate policy to date. Most formal analytical or numerical models focus on directly GHG-emitting capital stocks and direct measures such as carbon pricing, without separate representations of infrastructure and other indirectly emission-relevant capital stocks. This implies the assumption that a social planner or an idealized government optimally adjusts the composition of publicly provided goods (that are complementary to GHG-emitting private goods) so that the costs of (private) direct abatement are minimal. However, Shalizi and Lecocq (2010) argue that carbon pricing does not provide a sufficient signal for efficient investment into (public or private) long-lived capital stocks more generally, and that dedicated mitigation programs targeting these stocks are required.

However, this is not what we observe – instead, direct policies and infrastructure policies are often inconsistent: For example, many European countries that ratified the Kyoto protocol (and participate in the European Emissions Trading System) have not directed public infrastructure spending away from roads and airports and towards rail (ITF, 2014); commuter tax benefits persist in countries such as Germany, despite the importance of dense settlement patterns for transport emission reduction; while there is direct support for EV by price instruments in many European countries (Kley et al., 2010), public provision or support of electric vehicle charging infrastructure is rare, although the lack of charging infrastructure has been identified as a major obstacle to higher electric vehicle deployment (Sims et al., 2014). Efforts certainly fall far short of the adaptation of existing dirty capital stocks, or active policies to promote asset relocation, that Guivarch and Hallegatte (2011) consider necessary for reaching a 2 °C target.

Two recent studies do consider integrated environmental policy and point out the potential benefits. Waisman et al. (2012) use a second-best CGE where households and firms have imperfect foresight, and exogenously impose a specific set of adjustments of transport infrastructure and the related spatial asset distribution. They show numerically that this leads to significantly lower climate change mitigation costs, in particular in the long run: Beyond the mid-2030's, estimated costs of mitigation are lowered by 50% and more (and the carbon price is also drastically lowered). However, since the complementary measures are ad-hoc and exogenous, their (second-best) optimal level cannot be elucidated. Siegmeier (2016) analyzes a static model with two policy instruments: an environmental tax, and the ratio of spending on two publicly provided goods which are complementary to clean and dirty private consumption goods, respectively. He finds that when either the environmental tax rate or the public spending ratio is constrained below its first-best level, the second-best level of the other policy variable is also *lower* than its respective first-best (and a tighter constraint means an even lower second-best level of the other policy variable).

To reap the benefits of an integrated climate policy, a better understanding is needed of why governments have not optimally adjusted the structure of public capital stocks so far. Potential explanations include technological aspects (Shalizi and Lecocq, 2010, cf.): (1) uncertainty of technological de-

due to the public good characteristics of many crucial system elements, so the main arguments of this section still apply.

velopment, which weighs particularly heavily for long-lived public capital, (2) economies of scale for incumbent technologies and network effects, combined with the longevity of existing capital stocks, (3) long lead times for investment into infrastructure. Furthermore, institutional aspects may play a role, such as (4) conflicting competences (vertical externalities) between several levels of government, or (5) competition (horizontal externalities) between neighboring localities.

In sum, it seems likely that better integration of instruments directly targeting GHG emissions and complementary adjustments of public spending could yield significant welfare improvements. More research is required to determine the optimal balance between these two elements of climate policy, in particular in various scenarios with deficits of market- and government institutions.

3.4 Optimal public spending level: Alleviating budget constraints

In this section, we consider policy reforms that are not revenue-neutral and discuss when and how additional revenues from climate policy may improve welfare by increasing the total level of public spending, or by debt reduction. We first argue that revenue- and spending side effects of climate policy may lead to a larger optimal public budget. We then introduce the additional inefficiency that that the public spending level is sub-optimally low. We argue that additional revenues raised by climate policy may offer an opportunity to increase the public budget (closer) to its optimal size. Specifically, we review some empirical evidence that public capital is underprovided, potential explanations for this observation, and why revenue from climate policy may offer a remedy. Finally, the related topic of using climate policy revenues for public debt reduction is discussed.

The impact of climate policy when the public budget was previously (second-best) optimal

An optimal reaction in terms of public spending to the introduction of a consistent, stringent climate policy would be to adjust to a new (probably higher) spending level, for two reasons:

First, a given level of public funds may be raised at a lower cost when climate policy raises revenue via carbon pricing (see revenue-side arguments in Sections 2.2, 3.1 and 3.2).[11] Graphically, the curve of marginal costs of public funds is lower.

Second, the benefit that can be achieved at any level of public spending is likely to be higher under comprehensive climate policy: In some of the most emission-intensive sectors that require a transition to low-carbon technologies, public spending plays a particularly large role and will be more beneficial when it is adapted, e.g. infrastructure in energy and transportation (see Section 3.3). Public spending will also play a large role in adaptation to climate changes, and potentially in offsetting distributional effects of climate change (Section 3.5). Graphically, the curve of marginal benefits of public spending is higher.

[11] Goulder (2013) points out that ‘green taxes’ should not only be part of an optimal tax portfolio, but that even if the starting point is a sub-optimal distortionary tax system, additional revenue should come from a higher green tax rather than an ‘ordinary’ tax, as long as the green tax is not ‘too large’.

Together, this implies a larger public budget: the marginal cost- and benefit curves intersect at a higher spending level.[12] The increase in public spending in this new optimum may of course also include spending options that are unrelated to climate change, depending on the marginal benefit of each option.

Underprovision of public investment: why climate policy may help

Of course, the public budget is not always optimally sized in practice. There is evidence that public investment may be too low in many countries: Aschauer (1989) was the first to estimate a production function that includes public capital and found that public capital is undersupplied in the United States. Gramlich (1994) reviewed literature following up on Aschauer's study for the US and finds evidence for an undersupply at least for some types of public capital (e.g. urban transport infrastructure). More recently, Bom and Ligthart (2014) conducted a meta-regression analysis over 68 empirical studies for OECD countries. Their estimate for the output elasticity of public capital ranges from 0.08 (short-run effect of public capital broadly defined, at the national level) to 0.19 (long-run effect if only transport infrastructure and utilities at the regional level are included). Taking an approximate ratio of public capital to GDP of 0.5, this implies a marginal rate of return on public capital of 0.16 to 0.38. Comparing this to a depreciation rate of 0.1 and interest rate of 0.04, they conclude that public capital is indeed undersupplied.

We now consider four potential explanations for the non-optimal public budget, and why these problems may not apply or be weaker if additional revenues from climate policy are available:

First, public revenues may be too low due to weak institutions (this explanation will be more relevant for non-OECD countries). More specifically, institutions may be ineffective at implementing or enforcing conventional taxes, e.g. on income or consumption. Enforcing a carbon price may be less demanding, in particular when it is done upstream (fossil fuels consumption is relatively easy to measure). Political feasibility remains an issue though, since many implementations of a carbon price are visible to consumers (gasoline prices), and carbon pricing may affect rents from fossil fuels and/or existing energy- and carbon-intensive capital stocks.

Second, the existing allocation of other public funds may be inefficient in the sense that spending does not maximize net benefits. For example, when conventional taxes were introduced or increased in the past, political feasibility might have required the earmarking of revenues from specific taxes for specific spending (Wagner, 1991). But even if the allocation of revenues from other taxes cannot be changed, the new revenues from climate policy can be allocated freely to different spending options, at least initially.[13]

[12] When public investment is financed by taxing the rents on fixed factors (along the lines of a Henry George Theorem, see Arnott and Stiglitz (1979)), it may even be possible to establish the socially optimal allocation, see Mattauch et al. (2013). However, given a situation in which there are two externalities, related to the climate and to productive infrastructure which is publicly funded, it is unclear if the social optimum can be reproduced by using the revenues from correcting the climate externality to finance the public investment.

[13] Of course, for the same political economy reasons that led to an earmarking of non-carbon pricing revenues, a climate policy package may also contain restrictions on how to use carbon pricing revenues, e.g. for spending on climate change mitigation measures. As long as public spending on mitigation is marginally productive - which is probably currently the case, given the weakness of climate policy - it still constitutes a welfare improvement, even though there

Third, imperfect altruism towards future generations, or myopic politicians, may lead to high discounting of future benefits and thus to too little investment into projects with long-term benefits, which make up a substantial part of the public budget. If this were true, choosing stringent climate policy would be inconsistent, absent some mechanism that lets current generations benefit from future avoided damages (e.g. increasing asset prices, see Section 3.6). If climate policy was chosen nevertheless, it would under these circumstances more likely be designed in a revenue-neutral way, i.e. combined with cutting other distortionary taxes rather than an increase in the public budget - or at least a budget increase would probably not be in favor of projects with long-term benefits. Among the latter, mitigation policy still may stand the highest chances of realization, if the political momentum for climate policy is strong enough to lead to an 'earmarking' of climate policy revenues for mitigation spending, as discussed above.

Fourth, even if investments with long-term benefits were supported for the sake of future generations, there may be a lack of fiscal tools for financing their high up-front costs, e.g. political limits on public debt such as a maximum ratio of total or new debt to GDP (if the limit is set by financial markets due to doubts about a country's creditworthiness, this can often be traced back to weak institutions or inefficient political processes, which we already discussed above as the first two potential explanations of public underfunding). Then, additional revenues from climate policy may indeed offer more flexibility to invest in long-term projects. A related option that is discussed more prominently is using climate policy revenues for the reduction of public debt, which is covered next.

Public debt reduction

High levels of public debt have increasingly come into focus of policy makers, especially after their dramatic increase in developed countries as a result of the financial crisis. This is linked to the issue of climate change, as both are long-term challenges concerning many future generations.

Whether the existence of public debt in itself has a deteriorating effect on the economy is discussed controversially in the empirical literature (Kumar and Woo, 2010; Herndon et al., 2013), and to our knowledge not clearly supported by theory. In our view, the literature on public debt and climate policy (Carbone et al., 2012; Ramseur et al., 2012; Rausch, 2013) does also not give a genuinely new argument of why debt would by inefficient. Instead, the additional inefficiency that comes with the inclusion of public debt is represented through a government that fails to pay off the debt in an optimal way. This combines two effects that we treat in other sections:

First, debt reduction using revenue generated by climate policy can be less costly than financing it by other taxes - this is the classical double-dividend argument, as discussed in Section 2.2.

Second, revenue from climate policy can also help governments to optimize the intertemporal distribution of debt repayment - this is an argument regarding inter-generational distribution, worked out in more detail in Section 3.6.

may be better uses for at least some part of the funds. See Burtraw and Sekar (2014) for data on the use of revenues from currently existing carbon pricing schemes, or Brett and Keen (2000) for an attempt to explain earmarking of environmental taxes.

For example, both effects are captured by Rausch (2013): Using a numerical model, he finds that a revenue-neutral inclusion of a carbon tax in the tax portfolio would entail a gross welfare loss. But since the availability of the carbon tax also opens the possibility to raise additional revenue (at lower marginal costs of public funds) which can then be used to reduce the public debt, future interest payments can be avoided and welfare improved (even before taking avoided climate damages into account). This obviously has strong implications for the inter-generational distribution of welfare, as both the benefits from avoided environmental damages and those from lower interest payments on public debt would accrue to future generations, leaving today's generations at a loss. It has been argued elsewhere that the opposite approach, leaving future generations with more public debt, but an improved environment may be a way to finance mitigation measures today (see Section 3.6).

3.5 Using carbon revenues for reducing inequality: the role of public investment

So far, we have considered interactions of climate policy and public finance at the aggregate level, both concerning the levying of revenue from limiting emissions as well as alternatives for spending these revenues - and tacitly made the assumption that households are homogeneous. Distributive effects both on the revenue-raising and spending side become important in two cases: First, if inequality of income or wealth is taken to be undesirable as such (reflected by a specific concept of social welfare); second, if some types of inequality lead to aggregate inefficiency (which is our focus here).

Climate policy is likely to be regressive (Bento, 2013) and may thus increase inequality, which in turn could harm overall economic performance (Berg and Ostry, 2011; Berg et al., 2012; Kumhof et al., 2015). Recent publications treating household heterogeneity and climate policy demonstrate that it is possible to reduce or even eliminate the regressivity of climate policies by a carefully chosen recycling of the revenues. There are several mechanisms for this: Most of the literature focuses on household transfers and cuts in distorting taxes and finds that regressivity can be reduced, or even eliminated (Bureau, 2011; Metcalf, 1999; Chiroleu-Assouline and Fodha, 2009; Rausch et al., 2010). In contrast, how the financing of public investment with climate policy revenues affects the regressivity of these policies and thereby the overall efficiency remains unexplored. We suggest that if inequality is indeed harmful to overall economic performance, then such a policy could be another reason for lower welfare losses from climate change mitigation. Alternatively, if inequality reduction is valued as such, whether or not it impacts aggregate efficiency, social welfare is increased by combining climate policy with appropriate revenue recycling options that may alleviate, not increase inequality.

We subsequently first explain why climate policy is often considered regressive and which remedies have been proposed for this. We find broad agreement in the literature that recycling the revenues through household transfers and tax cuts drastically reduces the overall regressivity. Second, we explore whether inequality reduces economic efficiency and we find that in particular inequality of opportunities is detrimental to overall economic performance. Third, we argue that this strengthens the case for public investment as another remedy for inequality of opportunity, notably investment in education (OECD, 2012). Finally, we integrate the first and the third argument by raising the question to which degree the regressivity of climate policy could be offset by using its revenues specifically for public investment.

Environmental taxation: regressivity and remedies

Research on the equity impacts of climate policy has focused on factors that may make policy instruments regressive while neglecting the question of how revenue-recycling may achieve distributional goals (Bento, 2013). Following Fullerton (2011), there are several reasons why environmental policies can be regressive: The two most important effects are that, first, low income households spend a larger portion of their income on products which require fossil inputs. Environmental policy would increase the price of these goods and thus be regressive. Second, unskilled workers might lose their jobs in the polluting industry, while jobs in the renewable sector preferably go to high-skilled workers.[14]

Bento (2013) reviews recent empirical literature and finds that environmental policies are likely to have a regressive effect. Furthermore there is wide agreement that the revenues from environmental policies can be used to mitigate these regressive effects (Metcalf, 1999; Chiroleu-Assouline and Fodha, 2009; Bento et al., 2009; Bureau, 2011; Parry and Williams III, 2010). There may even exist ways to implement Pareto-improving environmental policies in a heterogeneous household setting.

Theoretical work that accounts for revenue recycling mainly focuses on households' transfers and cutting distorting taxes with climate policy revenues to mitigate regressivity: Chiroleu-Assouline and Fodha (2011, 2014) use an overlapping generations approach where agents differ in their skill level and their time preference rate to analyze budget-neutral carbon tax reforms. They show that for any degree of regressivity of a carbon tax, the tax revenue can be used for a progressive reform of the income tax system that renders the tax reform Pareto-improving. In their framework, pollution is a by-product of capital used in the production sector and climate policy hence acts like a capital tax. The studies mention the existence of a subsistence level of carbon-intensive consumption as an important driver of the regressivity of climate policy but do not model it explicitly.

Klenert and Mattauch (2016) and Klenert et al. (2016b) also confirm that redistribution of the carbon tax revenue can make an (otherwise regressive) carbon tax reform Pareto-improving. In contrast to previous work, they explicitly take into account that the poorer a household, the more of its income it spends on carbon-intensive subsistence goods, thus addressing the first concern about inequality regarding climate policy raised above.

[14]Other distributional effects of environmental policies are: First, for capital-intensive abatement technologies, environmental policies would drive up the demand for capital. This would depress wages which would have a regressive effect since low-income households receive most of their income from wages. Second, when pollution permits are grandfathered to firms, scarcity rents are created, which again go to the high-income firm owners (Parry, 2004). Third, low-income households may attach a lower value to environmental quality and care more for goods like food and shelter. Thus high-income households would benefit more from avoided damages. Fourth, avoided damages to capital increase the present value of capital, for example of an oceanfront house. Since capital owners are already better off, this policy would also have a regressive effect.

Rausch et al. (2010) look at a broader range of revenue redistribution mechanisms, such as transfers and tax cuts, in a more detailed general equilibrium model which is calibrated to the US economy. They find that the tax itself can have a slightly progressive effect, due to the dependence of poor households from transfer payments, which are unaffected by climate policies. Accounting for revenue recycling renders the tax reform even more progressive.

Does inequality reduce economic efficiency?

The conventional view of economic theory is that inequality reduction as a policy goal reduces the overall efficiency of an economy due to losses in the redistribution process (Okun, 1975). In particular, Kaldor (1955), based on the observation that rich households save more than poor households, comes to the conclusion that redistributive policies would thus lead to less capital accumulation. In the context of environmental taxation, Metcalf (1999) and Parry and Williams III (2010) point out that there is a trade-off between efficiency and the degree of reduced regressivity: more efficient environmental policies tend to be more regressive.[15]

However, the conventional view neglects that there are two fundamentally different types of inequality: inequality of opportunity is caused by factors which are beyond an individual's personal responsibility, like the economic situation of the parents (Roemer, 1993). In contrast, inequality of returns to efforts gives incentives to households to work harder. The conventional view is correct with respect to inequality of returns to efforts as it increases an economy's growth rate; however inequality of opportunities decreases it (Marrero and Rodríguez, 2013). High levels of inequality of opportunity are usually coupled to low social mobility, a fact which is also known as the 'Great Gatsby Curve' (Corak, 2013).

Berg and Ostry (2011) and Berg et al. (2012) look at growth in the long term and find that a trade-off between equity and efficiency might not exist. It rather seems that in countries with low economic inequality, the length of periods of strong economic growth, so-called 'growth spells', is increased. Moreover, Kumhof et al. (2015) claim that increased inequality and debt-to-income ratios can trigger economic crises, based on an analysis of the economic crises in the U.S., 1929 and 2007, which both were foreshadowed by a strong increase in wealth and welfare inequality.[16]

Additionally, inequality has been found to increase the risk of civil conflicts (Ostby, 2008; Ostby and Strand, 2013; Cederman et al., 2011), which in turn reduce growth.

[15]Burtraw and Sekar (2014) highlight that treating efficiency and equity as two objectives between which a government needs to strike a balance reflects a view where the atmosphere is owned by the state. In contrast, "if one views the property right to atmosphere resources as inherently assigned to individuals and held in common, the issue of how to use the economic value created from introducing a price on carbon might be viewed as illegitimate, at least from the perspective of the resource owner" (Burtraw and Sekar, 2014, p.4f).

[16]Additionally, it is debated whether inequality harms aggregate welfare by increasing health and social problems - independently of its impact on economic growth (Wilkinson and Pickett, 2009). A part of the debate is summarized in Noble (2009) and Liebig (2012).

Reducing inequality while promoting efficiency via public spending

High inequality of opportunity makes health care, education and other factors unaffordable for some parts of the population. This situation can partially be alleviated by public spending (OECD, 2012). A short-term impact of education on inequality of opportunity can in particular be expected from measures such as further training of unemployed or continued education for more senior workers in order to include or keep them in the labor market as well as language courses for immigrants.

Additionally, public investment in physical infrastructure is known to promote efficiency and growth (Romp and De Haan, 2007; Agénor, 2013), but the empirical literature regarding its effect on inequality is inconclusive: while some studies find that investment in infrastructure, which is financed by distorting taxes, reduces inequality (Calderón and Chong, 2004; Calderón and Servén, 2004; Lustig et al., 2011; Jacoby, 2000), there is also evidence for increased inequality through public spending (Artadi and Sala-I-Martin, 2003).

The theoretical literature is similarly ambiguous: In a growth model with heterogeneous dynastic agents, Chatterjee and Turnovsky (2012) show that government spending increases inequality in welfare and wealth in the long run. Glomm and Ravikumar (1994) find that income tax-financed public spending is neutral on the income distribution. Mattauch et al. (2016) and Klenert et al. (2016a) show in a heterogeneous-agent model that Pareto-improving public spending can have a distribution-neutral effect when it is financed by a tax on consumption, and even an inequality-reducing effect when financed by a tax on capital. In their model, agents are distinguished by their saving motive, their time preference and their source of income. These assumptions are well founded in the empirical literature[17] and are necessary to reproduce a realistic wealth distribution (De Nardi, 2004; De Nardi and Yang, 2014).

Financing public investment by carbon pricing

Combining the aspects discussed above raises two additional points: First, instead of directly redistributing revenues from carbon taxes (to mitigate their regressivity) or cutting distortionary taxes (which could also enhance inequality, see Klenert et al. (2016b)), governments could also invest in infrastructure to enhance growth. The resulting higher living standards of most households may alleviate inequality of opportunity directly. Second, climate policy revenues could be used for public investments that specifically reduce intragenerational inequality. What is unclear in both cases is the size of the inequality-reducing effect that climate policy revenues alone could finance. Future work on this would need to model household heterogeneity to reflect both the regressivity of environmental taxation as well as differential benefits from public investment. If the result was that for inequality reduction, public investment is preferable to direct financial benefits to poor households, then discussions of mitigating the regressive nature of environmental policies should focus on this option.

[17] Attanasio (1994), Dynan et al. (2004) and Browning and Lusardi (1996) demonstrate that the savings motive varies across income classes. Quadrini and Ríos-Rull (1997), Diaz-Gimenez et al. (2011) and Wolff (1998) highlight the role of different income sources and Lawrance (1991) show that households' time preference rate decreases the more wealth they own.

3.6 Intergenerational distribution: fiscal strategies for Pareto-improving climate policy

Climate change is fundamentally an intertemporal problem: If climate policy is to avert dangerous anthropogenic interference with the climate system, then substantial mitigation costs arise today, but much higher benefits through avoided damages occur in the future.

So the net costs of climate change could be lower at each point in time, if climate policy were combined with intergenerational redistribution: Future generations as the main beneficiaries of mitigation measures could be made to bear some of today's mitigation costs by a transfer to present generations. The resources for financing low-carbon infrastructures and emission reductions could thus be mobilized from future generations who have higher benefits from climate protection than the current population.

Such a transfer may be welfare-enhancing because it could achieve a Pareto-improvement, that is, negative net costs of climate policy in this context. Combining climate policy with intergenerational transfers that make it Pareto-improving could be a politically feasible solution to the climate problem: Given the standstill in international negotiations, Pareto-improving climate policy would separate the solution of the climate problem from the more general (and politically even more difficult) considerations of intergenerational justice (Broome, 2012). It differs from socially optimal climate policy by violating the optimal intergenerational distribution of welfare, but could potentially imply negative net costs of climate policy at each point in time.

But is Pareto-improving climate policy possible? Could intergenerational transfers from people yet unborn to those alive be implemented by fiscal policy? Recently different possibilities for such transfers have been explored. The remainder of this section first clarifies the above argument about Pareto-improving climate policy and then discusses suggestions for organizing an intergenerational transfer from the future to the present.

There is universal agreement about the basic economics of the climate problem: Climate change is a market failure as the emission of greenhouse gases are an externality. Economic theory holds that the correction of this externality comes at no cost. Some theorists have thus claimed that there really are no costs of climate change if those who will benefit from mitigation pay for it (Foley, 2008; Broome, 2010, 2012). However, climate change is an externality spread out over time so that rather than saying that there are no (net) costs of climate change, it seems more apt to conclude that there are net costs of climate change mitigation today, while higher benefits occur in the future. Thus only by arranging for an intergenerational transfer from the future beneficiaries of climate policy to the present generation that has to bear the costs of low-carbon investments, a Pareto-improving solution to the climate problem could be reached: no generation would need to pay more for climate change mitigation than the benefits it will receive. But only when climate mitigation policy is thus complemented by carefully designed transfer measures should there not be net costs to the present generation.

Recent research has considered two options for organizing intergenerational transfers: Diminution of capital stocks, and higher returns for current holders of assets such as fixed factors of production. An earlier strand of research has investigated a third option: public debt. Most of these options cannot be examined in representative-agent models, so that modeling is usually carried out using overlapping-generations models.

First, an obvious possibility for a transfer from future to current generations would be that current generations leave future generations less (private or public) capital in return for a cooler world (Foley, 2008; Broome, 2012). Rezai et al. (2012) use a variant of the DICE model (Nordhaus, 1993) to examine the possibility of financing mitigation with resources diverted from other investments. They find that implementing the social optimum compared to a true business-as-usual scenario[18] leads to higher consumption for all future people except those living in the first decade. Moreover, a more equity-conscious social planner, mimicking an intergenerational transfer, would want to allocate more consumption to the first decade, leading to a Pareto improvement for all generations. However a mechanism to achieve this based on tax policy instruments is not described.

On the contrary, von Below et al. (2013) propose a mechanism based on pay-as-you-go (PAYG) pensions between generations, using an overlapping-generations model. Therein, the old generations are compensated for their mitigation efforts by the respective young generation alive at the same time through a PAYG transfer payment. With this transfer scheme extending far into the future, a mitigation policy that is Pareto-improving for all generations can be achieved.

This result may be very sensitive to the way of modeling the PAYG transfers. Governments usually must rely on distortive taxation, typically on wage income, to finance the transfers which results in additional welfare losses. von Below et al. (2013) collect the PAYG pensions in a lump-sum fashion, which makes the proposed mechanism less useful for real-world fiscal policy.

A second possibility to organize an intergenerational transfer builds on the idea that climate change mitigation will change the value of current assets: their future returns will differ from a business-as-usual scenario due to fewer damages to production in the future. Karp and Rezai (2014b) demonstrate in a stylized overlapping-generations model that if agents live for two periods, capital is a fixed production factor and agents only own assets when they are old, a Pareto-improving transfer is possible in the following sense: If the mitigation of an externality requires investments today, all generations' welfare is improved except that of the current young. Their welfare can also be improved if the current old compensate them with a share of their increased asset value. Karp and Rezai (2014a) confirm this result for a non-fixed capital stock with adjustment costs between investment and consumption as well as standard dynamics of the atmospheric stock.

However, one may doubt whether such a model captures the relevant features of asset-holders behavior. The premise that future generations would pay today's proprietors higher prices for assets if future rents were higher due to mitigation measures today seems credible. But then rational proprietors today would welcome or execute investment in climate-friendly infrastructure, which largely does not conform to the current economic reality. Possible reasons for this mismatch include free-riding behavior, commitment problems, lack of information and imperfect foresight or time inconsistency.

[18]In which agents are deprived of mitigation instruments and do not see themselves capable of influencing the level of emissions.

Another possible explanation for this mismatch is brought forward by Schultes et al. (2015). In a setting similar to that of Karp and Rezai (2014a), today's generations have a stake in future avoided damages through the only durable asset model, land in their case. While this also leads to non-altruistic generations enacting some climate policy, they find that the level of mitigation depends on the type of damages: For damages biased towards land, the incentive to mitigate is diminished, as mitigation would decrease the price of land. In effect then, today's generations may decide to mitigate very little because they wish not to diminish future scarcity rents accruing to the durable assets they own.

A third, earlier line of inquiry has focused on constructing an intergenerational transfer by debt policy. When the Ricardian equivalence does not hold, it is possible to compensate current generations for their welfare losses from mitigation by transfer payments that are financed by increasing public debt. For instance Bovenberg and Heijdra (1998, 2002) find that environmental tax policy can be Pareto-improving when combined with public debt in a continuous overlapping-generations model. However their results hinge on a number of assumptions of which it is unclear whether they are a credible representation of the climate problem. Environmental degradation depends on the size of the capital stock, and harms utility, not production. Mitigation is only possible through either taxation (and thus reduction) of capital Bovenberg and Heijdra (1998) or public abatement spending Bovenberg and Heijdra (2002). These modeling assumption make it difficult to compare these earlier results to contemporary findings.

In sum, climate change mitigation in principle does not require sacrifices from the current generation in order to benefit future generations if these could be made to bear some of the costs of decarbonization. The net costs of climate change mitigation for the near future could thus be lower or even non-existing if an appropriate Pareto-improving intergenerational transfer can be realized. On a theoretical level, recent research has identified several options open to fiscal policy to organize such a transfer, although the robustness of the proposed mechanisms is unclear. On a practical level, political feasibility of committing long into the future to elaborate intergenerational transfers may well be doubted and is a topic for further research.

4 Discussion: Integrating climate policy and public finance in one framework

The thesis defended in this article – that taking into account the interactions between public finance and policies leads to welfare gains relative to treating the two fields in isolation – is dependent on two premises. The first premise concerns the framework of economic policy evaluation: Climate policy happens in a world with multiple market failures and pre-existing distortions (for instance due to taxes) which are in turn influenced by climate policy. We assume that models designed to evaluate climate policy should take these into account. Otherwise effects that might substantially change the outcome of the evaluation will be missed. The second premise concerns the benchmark of evaluation: Compared to standard discounted utilitarianism, if (intragenerational) equality is valuable as such (see Section 3.5) one may find that welfare gains are larger compared to evaluations under discounted utilitarianism. Seeking intergenerational Pareto-improvements instead of intertemporal optimality (see Section 3.6) reinforces this conclusion. The following discussion focuses on the first premise and justifies why it is appropriate to consider the welfare effects of climate change in a framework that also includes other fiscal policy objectives.[19]

From a practitioner's perspective, there is a straightforward answer to this question: Whenever substantial interactions between two distinct fields exist, one should include these interactions into policy appraisal. This is particularly true if such interactions become tangible in terms of large financial flows, as is the case for interactions between climate change mitigation and public finance: If mitigation efforts yield revenues that can form a substantial part of national budgets (see Section 1), policy-makers will de facto be concerned with the interactions of climate policy with fiscal policy.

To the theorist, such an answer may seem naïve. We discuss - and rebut - two major objections to the practitioner's perspective. The first objection concerns the legitimacy of treating certain economic phenomena together and not in isolation. The second is the doubt that through the advent of a 'new' problem to be addressed by policy, addressing existing imperfections becomes any more feasible or actually yields a genuine benefit.

Regarding the first objection, the question to which degree abstraction, simplification and isolation is warranted in economic theory is arguably the most important methodological problem for economics (Hausman, 2013). Hence whether merging two previously unrelated subfields is considered an improvement over previous research may fundamentally depend on one's basic methodological commitments. Examining these for the case of merging climate policy with major topics of public finance is beyond the scope of this article. However, the thesis that embedding analysis of climate policy in a public finance framework results in non-negligible effects for both fields is a theoretically very modest claim. We do not know of any metaphysical, methodological or normative controversy (see (Mäki, 1992, section 10)) that would provide arguments for or against merging the two fields; on the contrary doing so is likely to yield sounder policy advice. Current greater interest (or earlier lack thereof) in linking the fields of public finance and climate change mitigation may thus need to be discussed differently: first, evidence for the fact that linking the two fields would yield truly non-negligible effects is provided by relatively recent studies (Metcalf, 2007; Bauer et al., 2013; Carbone et al., 2013) that show that ambitious climate protection will yield substantial revenues for government budgets. Second, economic research is typically conducted with a narrow focus on the essentials of a problem, sometimes at risk of missing some of its broader implications. Already Tullock (1967, p.643), who may have been the first to note a potential double dividend of environmental taxation, remarks that "*economists, like everyone else, sometimes keep ideas in watertight compartments. Fiscal policy has normally been dealt with quite separately from the problem of externalities*". Goulder (1995a, footnote 3) reinforces this claim when writing that "*the neglect of these interactions reflects a tradition*

[19]For extensive discussions about the appropriateness of discounted standard utilitarianism for evaluating climate change and alternative welfare criteria concerning intra- and intergenerational equity, see e.g. Dasgupta (2001); Roemer (2011); Broome (2012). As there is a very prominent debate within climate change economics about the benchmark for evaluating policies, our discussion is limited to a justification of the first premise.

in the field of public finance, where theoretical analysis of pollution taxes [...] has generally been kept separate from the analysis of ordinary distortionary taxes". Combet (2013) and Combet and Hourcade (2014) defend a view similar to that of this article for the case of interactions of climate policy with the social security system. The reply to the first theoretical objection thus bolsters the intuition implicit in the practitioner's perspective.

Regarding the second objection, the theorist will wonder why the advent of stricter climate policy will impact the success of policy to address other externalities. Why would the introduction of climate policy imply that other unrelated real-world imperfections should suddenly be addressed in combination with the climate policy instrument? If public spending is non-optimally composed, inequality imperfectly addressed, public debt at non-optimal levels, etc., there should be reasons independent of climate policy why this is so and a reason why this may be changed if climate policy is enacted. One answer to this objection comes from economic theory; another answer from political economy.

The theory of second-best allocations stresses that in a situation in which one externality is not corrected, the optimal allocation on all other markets differs from the first-best allocation (Lipsey and Lancaster, 1956). Thus if one moves from a situation in which the climate externality is unaddressed to one in which it is addressed, in general some other regulated market equilibria should be changed as well to achieve the first-best outcome. Some of the effects considered in Sections 2 and 3 indeed confirm that adjusting policy measures supposed to address distortions independent of climate policy does have beneficial effects when stricter climate policy is introduced.

A different answer to this objection complements the practitioner's perspective by infusing it with political economy. Politically, it is typically more feasible to design tax reforms that combine various public finance measures tailored to win the support of special interest groups (Grossman and Helpman, 2001) and voters (Castanheira et al., 2012). In particular, the government may be constrained by not being able to raise non-environmental, distortionary taxes on political grounds, even if levying these taxes to increase government spending would increase total productivity. Poterba (1993, p.55) stresses this point: "*On reflection the [double dividend argument] may make more sense. If there is a causal link between enacting a carbon tax and cutting particular other taxes, perhaps because of political constraints on raising existing taxes, and if there are no other ways to enact changes in these other taxes, then it is appropriate to consider how the funds are used in evaluating the net benefit from a carbon tax*".

Recent work in climate economics has been impacted by similar, but even broader considerations: Opinions differ on whether to include beneficial side-effects of climate change mitigation that are not of fiscal nature, often labeled 'co-benefits' (Haines et al., 2009; West et al., 2013; Ürge-Vorsatz et al., 2014) - such as improved health through reduction of local air pollution and increased model share of non-motorized transport, or energy security - into cost assessments of climate policy (Nemet et al., 2010; Kolstad et al., 2014; Edenhofer et al., 2015a).[20] Arguments in favor of the inclusion of co-benefits in pol-

[20]The effects studied in Section 3 can be seen as 'co-benefits' of climate change mitigation if the term is to include all beneficial side effects of climate policy. However as some of the effects mentioned in this article are non-incremental and /or have intertemporal ramifications, it is at

icy appraisal based on welfare theory are similar to those already given for fiscal interactions of climate policy (greater realism of effects of climate policy; sounder policy advice). We conclude the discussion of merging analysis of fiscal and climate policy by indicating why the two principal objections prominent in the co-benefit debate do not apply to fiscal side-effects of climate change mitigation.

A first principal objection against accounting for non-fiscal co-benefits is that studies of their magnitude do not happen in a framework suitable for welfare analysis. This may be the case for studies mostly analyzing a specific sector in one location, although some studies do assess the welfare effects of policy options (IPCC, 2014). This is an objection less acute for fiscal co-benefits of climate change mitigation such as those scrutinized in Section 3 as research on interactions of mitigation policy with other fiscal policy has typically been analyzed in general equilibrium contexts.

A different objection against the inclusion of co-benefits in cost assessments of climate policy is that the uncertainty around some side effects of climate policy is too great to include them into policy appraisal. Even if many co-benefits are said to be less uncertain than future mitigation benefits, estimates of the uncertainties might still be incommensurable (Nemet et al., 2010; West et al., 2013). A further worry is that these effects are difficult to monetize (Ürge-Vorsatz et al., 2014). Whether or not this critique is legitimate (Edenhofer et al., 2013, 2014; von Stechow et al., 2015), it does not apply to public finance co-benefits: Estimates of the revenue from carbon taxation and of the size of other fiscal interactions are both relatively robust and such estimates are already expressed in monetary terms.

5 Conclusion: Implications for Policy Assessment

This article highlighted the close links between climate change mitigation and other, allegedly conflicting objectives of economic policy such as financing public investment or reducing tax competition and inequality. These links include, but go far beyond the idea of a potential 'double dividend' of substituting environmental for distortionary taxes. It has been shown that the welfare effects of climate policy should be assessed in a comprehensive public finance framework, and that this reveals efficiency gains. There may also be more flexibility in terms of the intra- and intergenerational distribution of costs, helping to avoid potential conflict over carbon tax reforms.

We conclude by highlighting some consequences for the assessment of climate policy and public finance research:

Concerning the assessment of climate policy, IAMs have generally been designed to include as many effects relevant climate change mitigation as possible.[21] Some of the arguments given above to support the thesis of this article have been endorsed by the integrated assessment community to justify the inclusion of as many technological options as possible for the assessment

present unclear how to incorporate them into the framework on co-benefits recently proposed by the IPCC (Kolstad et al., 2014).

[21]For instance, they have even been defined to *"(2) constructively force multiple dimensions of the climate change problem into the same framework, and (3) quantify the relative importance of climate change in the context of other environmental and non-environmental problems facing mankind."* (Kelly and Kolstad, 1999, p.3, summarizing Weyant et al. (1996)).

of climate policy (Schneider, 1997). If such assessments have a direct policy impact this may even be mandatory to prevent ‘cherry picking’ by lobby groups, that is the willful exclusion of relevant, but unwelcome effects. However, climate policy assessments have predominantly focused on technological options (Millner, 2013; Staub-Kaminski et al., 2014), neglecting interactions with public finance (Howarth, 2006). The contribution of this article thus underlines that integrating the above interactions of climate policy with topics in public finance could change results of climate policy assessments significantly.

Furthermore, IAMs have also been accused of insufficiently analyzing climate policy under welfare conceptions different from standard discounted utilitarianism (Howarth, 2000; Llavador et al., 2011; Millner, 2013). Regarding the significance of the two alternative welfare criteria employed in this article, intragenerational inequality reduction as an end in itself and intergenerational Pareto-improvements, it may thus be enlightening to conduct an assessment of climate policy with IAMs from these different viewpoints. There is preliminary evidence that applying these alternative welfare criteria indeed leads to markedly different evaluations of climate policy (see Rausch et al. (2011) for inequality reduction; Rezai et al. (2012) for Pareto-improvements).

Public finance vice versa typically neglects issues of climate policy, presumably because the field is unaware of the high fiscal revenues to be expected from ambitious climate policy. Exceptions are the classical double-dividend discussion (Goulder, 1995b, 2013) and a few applications to the problem of tax competition (Eichner and Runkel, 2012; Habla, 2014; Franks et al., 2015). But in an economy that will be significantly constrained by (mitigated or unmitigated) climate change (IPCC, 2014) the field should take ramifications of climate policy into account more, as the analysis of the major effects above has shown. The contribution of this article could thus also be seen as a first attempt to structure the mitigation effects to be included into a public economics of a climate-constrained world.

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References

Ackerman, F., DeCanio, S. J., Howarth, R. B., Sheeran, K., 2009. Limitations of integrated assessment models of climate change. Climatic Change 95(3-4), 297–315.

Agénor, P.-R., 2013. Public Capital, Growth and Welfare. Analytical Foundations for Public Policy. Princeton University Press.

Aldy, J. E., Krupnick, A. J., Newell, R. G., Parry, I. W. H., Pizer, W. A., 2010. Designing climate mitigation policy. Journal of Economic Literature 48(4), 903–934.

Arnott, R. J., Stiglitz, J. E., 1979. Aggregate land rents, expenditure on public goods, and optimal city size. Quarterly Journal of Economics 93(4), 471–500.

Artadi, E. V., Sala-I-Martin, X., 2003. The economic tragedy of the XXth century: Growth in africa. NBER Working Paper Series No. 9865.

Aschauer, D. A., 1989. Is public expenditure productive? Journal of Monetary Economics 23(2), 177–200.

Attanasio, O. P., 1994. Personal saving in the united states. In: Poterba, J. M. (Ed.), International Comparisons of Household Saving, pp. 57–124, The University of Chicago Press, Chicago.

Barrage, L., 2014. Optimal dynamic carbon taxes in a climate-economy model with distortionary fiscal policy. Working paper.

Bauer, N., Mouratiadou, I., Luderer, G., Baumstark, L., Brecha, R. J., Edenhofer, O., Kriegler, E., 2013. Global fossil energy markets and climate change mitigationâĂŞan analysis with ReMIND. Climatic Change pp. 1–14.

Bento, A. M., 2013. Equity impacts of environmental policy. Annual Review of Resource Economics 5, 181–196.

Bento, A. M., Goulder, L. H., Jacobsen, M. R., von Haefen, R. H., 2009. Distributional and efficiency impacts of increased US gasoline taxes. American Economic Review 99(3), 667–699.

Bento, A. M., Jacobsen, M., 2007. Ricardian rents, environmental policy and the 'double-dividend' hypothesis. Journal of Environmental Economics and Management 53(1), 17–31.

Berg, A., Ostry, J. D., Zettelmeyer, J., 2012. What makes growth sustained? Journal of Development Economics 98(2), 149 – 166.

Berg, A. G., Ostry, J. D., 2011. Inequality and unsustainable growth: Two sides of the same coin? IMF Staff Discussion Note SDN/11/08.

Bom, P. R., Ligthart, J. E., 2014. What have we learned from three decades of research on the productivity of public capital? Journal of Economic Surveys 28(5), 889–916.

Bosello, F., Carraro, C., Galeotti, M., 2001. The double dividend issue: modeling strategies and empirical findings. Environment and Development Economics 6(1), 9–45.

Bovenberg, A., Heijdra, B. J., 1998. Environmental tax policy and intergenerational distribution. Journal of Public Economics 67(1), 1–24.

Bovenberg, A. L., 1999. Green tax reforms and the double dividend: an updated reader's guide. International Tax and Public Finance 6(3), 421–443.

Bovenberg, A. L., De Mooij, R. A., 1994. Environmental levies and distortionary taxation. The American Economic Review 84(4), 1085–1089.

Bovenberg, A. L., de Mooij, R. A., 1997. Environmental tax reform and endogenous growth. Journal of Public Economics 63(2), 207–237.

Bovenberg, A. L., Heijdra, B. J., 2002. Environmental abatement and intergenerational distribution. Environmental and Resource Economics 23(1), 45–84.

Bovenberg, A. L., van der Ploeg, F., 1994. Environmental policy, public finance and the labour market in a second-best world. Journal of Public Economics 55(3), 349–390.

Brett, C., Keen, M., 2000. Political uncertainty and the earmarking of environmental taxes. Journal of Public Economics 75(3), 315–340.

Broome, J., 2010. The most important thing about climate change. In: Boston, J., Bradstock, A., Eng, D. (Eds.), Public Policy: Why Ethics Matters, pp. 101–116, ANU E Press, Canberra.

Broome, J., 2012. Climate matters. Ethics in a warming world. W.W. Norton & Company, New York.

Browning, M., Lusardi, A., 1996. Household saving: Micro theories and micro facts. Journal of Economic Literature 34(4), 1797–1855.

Bureau, B., 2011. Distributional effects of a carbon tax on car fuels in France. Energy Economics 33(1), 121–130.

Burtraw, D., Sekar, S., 2014. Two world views on carbon revenues. Journal of Environmental Studies and Sciences 4(1), 110–120.

Calderón, C., Chong, A., 2004. Volume and quality of infrastructure and the distribution of income: An empirical investigation. Review of Income and Wealth 50(1), 87–106.

Calderón, C. A., Servén, L., 2004. The effects of infrastructure development on growth and income distribution. World Bank Policy Research Working Paper No. 3400.

Carbone, J., Morgenstern, R. D., Williams III, R. C., Burtraw, D., 2013. Deficit reduction and carbon taxes: Budgetary, economic, and distributional impacts. Resources for the Future, report.

Carbone, J. C., Morgenstern, R. D., Williams III, R. C., 2012. Carbon taxes and deficit reduction. Working paper.

Carraro, C., Galeotti, M., Gallo, M., 1996. Environmental taxation and unemployment: Some evidence on the 'double dividend hypothesis' in europe. Journal of Public Economics 62(1–2), 141 – 181.

Castanheira, M., Nicodème, G., Profeta, P., 2012. On the political economics of tax reforms: survey and empirical assessment. International Tax and Public Finance 19(4), 598–624.

Cederman, L.-E., Weidmann, N. B., Gleditsch, K. S., 2011. Horizontal inequalities and ethnonationalist civil war: A global comparison. American Political Science Review 105(3), 478–495.

Chatterjee, S., Turnovsky, S. J., 2012. Infrastructure and inequality. European Economic Review 56(8), 1730–1745.

Chiroleu-Assouline, M., Fodha, M., 2009. Double dividend and distribution of welfare: advanced results and empirical considerations. Économie International 120(4), 91–107.

Chiroleu-Assouline, M., Fodha, M., 2011. Environmental tax and the distribution of income among heterogeneous workers. Annals of Economics and Statistics/Annales d'Économie et de Statistique 103/104, 71–92.

Chiroleu-Assouline, M., Fodha, M., 2014. From regressive pollution taxes to progressive environmental tax reforms. European Economic Review 69, 126 – 142.

Clarke, L., Jiang, K., Akimoto, K., Babiker, M., Blanford, G., Fisher-Vanden, K., Hourcade, J.-C., Krey, V., Kriegler, E., Löschel, A., McCollum, D., Paltsev, S., Rose, S., Shukla, P. R., Tavoni, M., van der Zwaan, B., van Vuuren, D., 2014. Assessing transformation pathways. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., Minx, J.-C. (Eds.), Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

Combet, E., 2013. Carbon taxation and social progress. Global Union Research Network Discussion Paper No.17 .

Combet, E., Hourcade, J.-C., 2014. Carbon tax, pensions and public deficits: The hidden costs of the compartmentalization of expertise. Mimeo.

Corak, M., 2013. Income inequality, equality of opportunity, and intergenerational mobility. Journal of Economic Perspectives 27(3), 79–102.

Dasgupta, P., 2001. Human Well-Being and the Natural Environment. Oxford University Press.

Dasgupta, P., 2007. Commentary: The Stern Review's economics of climate change. National Institute Economic Review 199, 4–7.

Davis, S. J., Caldeira, K., Matthews, H. D., 2010. Future CO2 emissions and climate change from existing energy infrastructure. Science 329(5997), 1330–1333.

de Mooij, R. A., Keen, M., Parry, I. W. H., 2012. Fiscal Policy to Mitigate Climate Change : A Guide for Policymakers. IMF eLibrary, USA.

De Nardi, M., 2004. Wealth inequality and intergenerational links. Review of Economic Studies 71(3), 743–768.

De Nardi, M., Yang, F., 2014. Bequests and Heterogeneity in Retirement Wealth. European Economic Review 72, 182–196.

Diaz-Gimenez, J., Glover, A., Ríos-Rull, J.-V., 2011. Facts on the distributions of earnings, income, and wealth in the United States: 2007 update. Federal Reserve Bank of Minneapolis Quarterly Review 34(1), 2–31.

Dynan, K. E., Skinner, J., Zeldes, S. P., 2004. Do the rich save more? Journal of Political Economy 112(2), 397–444.

Edenhofer, O., Jakob, M., Creutzig, F., Flachsland, C., Fuss, S., Kowarsch, M., Lessmann, K., Mattauch, L., Siegmeier, J., Steckel, J. C., 2015a. Closing the emission price gap. Global Environmental Change, forthcoming .

Edenhofer, O., Kadner, S., von Stechow, C., Schwerhoff, G., Luderer, G., 2014. Linking climate change mitigation research to sustainable development. In: Atkinson, G., Dietz, S., Neumayer, E., Agarwala, M. (Eds.), Handbook of Sustainable Development, Edward Elgar, 2nd edition.

Edenhofer, O., Mattauch, L., Siegmeier, J., 2015b. Hypergeorgism: When Rent Taxation is Socially Optimal. FinanzArchiv/Public Finance Analysis forthcoming.

Edenhofer, O., Seyboth, K., Creutzig, F., Schlömer, S., 2013. On the sustainability of renewable energy sources. Annual Review of Environment and Resources 38(1), 169–200.

Eichner, T., Runkel, M., 2012. Interjurisdictional spillovers, decentralized policymaking, and the elasticity of capital supply. American Economic Review 102(5), 2349–57.

Feldstein, M. S., 1977. The surprising incidence of a tax on pure rent: A new answer to an old question. Journal of Political Economy 85(2), 349–360.

Fischer, C., Heutel, G., 2013. Environmental macroeconomics: Environmental policy, business cycles, and directed technical change. Annual Review of Resource Economics 5, 197–210.

Fischer, C., Newell, R. G., 2008. Environmental and technology policies for climate mitigation. Journal of Environmental Economics and Management 55(2), 142–162.

Fischer, C., Preonas, L., 2010. Combining policies for renewable energy: Is the whole less than the sum of its parts? International Review of Environmental and Resource Economics 4(1), 51–92.

FitzRoy, F., 1996. Environmental taxes, non-separable externalitities and real wages. Working paper, University of St. Andrews.

Foley, D. K., 2008. The economic fundamentals of global warming. In: Harris, J. M., Goodwin, N. R. (Eds.), Twenty-First Century Macroeconomics: Responding to the Climate Challenge, Edward Elgar Publishing, Northampton.

Franks, M., Edenhofer, O., Lessmann, K., 2015. Why Finance Ministers Favor Carbon Taxes, Even if They Do Not Take Climate Change into Account. Environmental and Resource Economics, doi:10.1007/s10640-015-9982-1.

Fullerton, D., 2011. Six distributional effects of environmental policy: Six distributional effects of environmental policy. Risk Analysis 31(6), 923–929.

Gillingham, K., Newell, R. G., Palmer, K., 2009. Energy efficiency economics and policy. Annual Review of Resource Economics 1(1), 597–619.

Glomm, G., Ravikumar, B., 1994. Growth-inequality trade-offs in a model with public sector R&D. The Canadian Journal of Economics / Revue canadienne d'Economique 27(2), 484–493.

Goulder, L. H., 1995a. Effects of carbon taxes in an economy with prior tax distortions: An intertemporal equilibrium analysis. Journal of Environmental Economics and Management 29, 271–297.

Goulder, L. H., 1995b. Environmental taxation and the double dividend: a reader's guide. International Tax and Public Finance 2(2), 157–183.

Goulder, L. H., 2013. Climate change policy's interactions with the tax system. Energy Economics 40, S3–S11.

Gramlich, E. M., 1994. Infrastructure investment: a review essay. Journal of Economic Literature 32, 1176–1196.

Grossman, G. M., Helpman, E., 2001. Special interest politics. MIT Press.

Guivarch, C., Crassous, R., Sassi, O., Hallegatte, S., 2011. The costs of climate policies in a second best world with labour market imperfections. Climate Policy 11(1), 768–788.

Guivarch, C., Hallegatte, S., 2011. Existing infrastructure and the 2Âřc target: A letter. Climatic Change 109(3-4), 801–805.

Habla, W., 2014. Non-renewable resource extraction and interjurisdictional competition across space and time. Mimeo.

Haines, A., McMichael, A. J., Smith, K. R., Roberts, I., Woodcock, J., Markandya, A., Armstrong, B. G., Campbell-Lendrum, D., Dangour, A. D., Davies, M., Bruce, N., Tonne, C., Barrett, M., Wilkinson, P., 2009. Public health benefits of strategies to reduce greenhouse-gas emissions: overview and implications for policy makers. The Lancet 374(9707), 2104–2114.

Harris, J. M., 2013. Green Keynesianism: Beyond standard growth paradigms. Working Paper 13-02, Global Development and Environment Institute, Tufts University.

Hausman, D. M., 2013. Philosophy of economics. In: Zalta, E. N. (Ed.), The Stanford Encyclopedia of Philosophy (Winter 2013 Edition), http://plato.stanford.edu/archives/win2013/entries/economics/.

Herndon, T., Ash, M., Pollin, R., 2013. Does high public debt consistently stifle economic growth? A critique of Reinhart and Rogoff. Cambridge Journal of Economics 38(2), 257–279.

Hope, C., 2006. The marginal impact of CO2 from PAGE2002: An integrated assessment model incorporating the IPCC's five reasons for concern. Integrated Assessment 6(1), 19–56.

Howarth, R., 2000. Climate change and relative consumption. In: Jochem, E., Sathaye, J., Bouille, D. (Eds.), Society, Behaviour, and Climate Change Mitigation, *Advances in Global Change Research*, volume 8, pp. 191–206, Springer Netherlands.

Howarth, R. B., 2006. Optimal environmental taxes under relative consumption effects. Ecological Economics 58(1), 209–219.

IPCC, 2014. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Eds. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.-C. Minx. Cambridge University Press, Cambridge.

ITF, 2014. International Transport Forum, data on road and rail infrastructure investment, retrieved from http://stats.oecd.org on 2014-11-20.

Jacoby, H. G., 2000. Access to markets and the benefits of rural roads. The Economic Journal 110(465), 713–737.

Jones, B., Keen, M., Strand, J., 2012. Fiscal implications of climate change. World Bank Policy Research Working Paper No. 5956 .

Kaldor, N., 1955. Alternative theories of distribution. The Review of Economic Studies 23(2), 83–100.

Kalkuhl, M., Edenhofer, O., Lessmann, K., 2011. Learning or lockin: optimal technology policies to support mitigation. Resource and Energy Economics 34, 1–23.

Kalkuhl, M., Edenhofer, O., Lessmann, K., 2013. Renewable energy subsidies: Second-best policy or fatal aberration for mitigation? Resource and Energy Economics 35(3), 217–234.

Karp, L., 1984. Optimality and consistency in a differential game with nonrenewable resources. Journal of Economic Dynamics and Control 8(1), 73–97.

Karp, L., Rezai, A., 2014a. Asset prices and climate policy. Mimeo.

Karp, L., Rezai, A., 2014b. The political economy of environmental policy with overlapping generations. International Economic Review 55(3), 711–733.

Keen, M., 1998. Vertical tax externalities in the theory of fiscal federalim. IMF Staff Papers 45(3), 454–485.

Keen, M., Konrad, K. A., 2013. The theory of international tax competition and coordination. In: Alan J. Auerbach, M. F., Raj Chetty, Saez, E. (Eds.), Handbook of Public Economics, Vol. 5, pp. 257 – 328, Elsevier.

Kelly, D., Kolstad, C., 1999. Integrated assessment models for climate change control. In: Folmer, H., Tietenberg, T. (Eds.), International Yearbook of Environmental and Resource Economics 1999/2000: A Survey of Current Issues, pp. 171–197, Edward Elgar, Cheltenham, UK.

Klenert, D., Mattauch, L., 2016. How to make a carbon tax reform progressive: The role of subsistence consumption. Economics Letters 138, 100–103.

Klenert, D., Mattauch, L., Edenhofer, O., Lessmann, K., 2016a. Infrastructure and inequality: Insights from incorporating key economic facts about household heterogeneity. Macroeconomic Dynamics, doi:10.1017/S1365100516000432.

Klenert, D., Schwerhoff, G., Edenhofer, O., Mattauch, L., 2016b. Environmental taxation, inequality and Engel's law: The double dividend of redistribution. Environmental and Resource Economics, doi:10.1007/s10640-016-0070-y.

Kley, F., Wietschel, M., Dallinger, D., 2010. Evaluation of european electric vehicle support schemes. Working Papers Sustainability and Innovation No. S7/2010, Fraunhofer ISI, Germany.

Koethenbuerger, M., Poutvaara, P., 2009. Rent taxation and its intertemporal welfare effects in a small open economy. International Tax and Public Finance 16(5), 697–709.

Kolstad, C., Urama, K., Broome, J., Bruvoll, A., Carino Olvera, M., Fullerton, D., Gollier, C., Hanemann, W. M., Hassan, R., Jotzo, A., Khan, M. R., Meyer, L., Mundaca, S., 2014. Social, economic and ethical concepts and methods. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., Minx, J.-C. (Eds.), Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

Koskela, E., Schöb, R., 2002. Optimal factor income taxation in the presence of unemployment. Journal of Public Economic Theory 4(3), 387–404.

Koskela, E., Schöb, R., Sinn, H.-W., 1998. Pollution, factor taxation and unemployment. International Tax and Public Finance 5(3), 379–396.

Kumar, M., Woo, J., 2010. Public debt and growth. IMF Working Papers WP/10/174.

Kumhof, M., Rancière, R., Winant, P., 2015. Inequality, leverage and crises. American Economic Review 105(3), 1217–1245.

Lawrance, E. C., 1991. Poverty and the rate of time preference : Evidence from panel data. Journal of Political Economy 99(1), 54–77.

Liebig, S., 2012. Richard Wilkinson and Kate Pickett (2009): The spirit level. Why more equal societies almost always do better. Allen Lane, London. [Review]. Social Justice Research 25(1), 102–107.

Lipsey, R., Lancaster, K., 1956. The general theory of second best. The Review of Economic Studies 24(1), 11–32.

Liu, A. A., 2013. Tax evasion and optimal environmental taxes. Journal of Environmental Economics and Management 66(3), 656–670.

Llavador, H., Roemer, J. E., Silvestre, J., 2011. A dynamic analysis of human welfare in a warming planet. Journal of Public Economics 95(11), 1607–1620.

Luderer, G., Bosetti, V., Jakob, M., Leimbach, M., Steckel, J. C., Waisman, H., Edenhofer, O., 2012. The economics of decarbonizing the energy system – results and insights from the RECIPE model intercomparison. Climatic Change 114(1), 9–37.

Lustig, N., Lopez-Calva, L. F., Ortiz-Juarez, E., 2011. The decline in inequality in latin america: How much, since when and why. Society for the Study of Economic Inequality (ECINEQ) Working Paper 2011-211.

Mäki, U., 1992. On the method of isolation in economics. Poznan Studies in the Philosophy of the Sciences and the Humanities (special issue Idealization IV: Intelligibility in Science) 26, 319–354.

Markandya, A., González-Eguino, M., Escapa, M., 2013. From shadow to green: Linking environmental fiscal reforms and the informal economy. Energy Economics 40, Supplement 1, S108 – S118, supplement Issue: Fifth Atlantic Workshop in Energy and Environmental Economics.

Marrero, G. A., Rodríguez, J. G., 2013. Inequality of opportunity and growth. Journal of Development Economics 104, 107–122.

Mattauch, L., Creuzig, F., Edenhofer, O., 2015. Avoiding carbon lock-in: Policy options for advancing structural change. Economic Modelling 50, 49–63.

Mattauch, L., Edenhofer, O., Klenert, D., Bénard, S., 2016. Distributional effects of public investment when wealth and classes are back. Metroeconomica 67(3), 603–629.

Mattauch, L., Siegmeier, J., Edenhofer, O., Creutzig, F., 2013. Financing public capital through rent taxation. CESifo Working Paper No. 4280.

Metcalf, G. E., 1999. A distributional analysis of green tax reforms. National Tax Journal 52(4), 655–681.

Metcalf, G. E., 2007. A proposal for a U.S. carbon tax swap: An equitable tax reform to address global climate change. Discussion Paper 2007-12, Hamilton Project, Brookings Institute. .

Millner, A., 2013. On welfare frameworks and catastrophic climate risks. Journal of Environmental Economics and Management 65(2), 310–325.

Nemet, G., Holloway, T., Meier, P., 2010. Implications of incorporating air-quality co-benefits into climate change policymaking. Environmental Research Letters 5(1), 014007.

Noble, H., 2009. Comments on the spirit level controversy. Radical Statistics 104, 49–60.

Nordhaus, W. D., 1993. Rolling the 'DICE': An optimal transition path for controlling greenhouse gases. Resource And Energy Economics 15, 27–50.

Nordhaus, W. D., 2007. A review of the Stern Review on the economics of climate change. Journal of Economic Literature 45(3), 686–702.

OECD, 2012. Ch.5: Reducing income inequality while boosting economic growth: Can it be done? In: Economic Policy Reforms 2012: Going for Growth, OECD Publishing.

Okun, A. M., 1975. Equality and efficiency: The big tradeoff. Brookings Institution Press.

Ostby, G., 2008. Horizontal inequalities, the political environment and civil conflict: Evidence from 55 developing countries. In: Stewart, F. (Ed.), Horizontal Inequalities and Conflict: Understanding Group Violence in Multiethnic Societies, pp. 136–157, Palgrave Macmillan.

Ostby, G., Strand, H., 2013. Horizontal inequalities and internal conflict: The impact of regime type and political leadership regulation. In: Kalu, K., Uzodike, U. O., Kraybill, D., Moolakkatu, J. (Eds.), Territoriality, Citizenship, and Peacebuilding: Perspectives on Challenges to Peace in Africa, pp. 139–188, Adonis & Abbey.

Parry, I. W., 1995. Pollution taxes and revenue recycling. Journal of Environmental Economics and Management 29, S64–S77.

Parry, I. W., Williams III, R. C., 2010. What are the costs of meeting distributional objectives for climate policy? The BE Journal of Economic Analysis & Policy 10(2).

Parry, I. W. H., 2004. Are emissions permits regressive? Journal of Environmental Economics and Management 47(2), 364–387.

Pearce, D., 1991. The role of carbon taxes in adjusting to global warming. The Economic Journal 101(407), 938–948.

Petrucci, A., 2006. The incidence of a tax on pure rent in a small open economy. Journal of Public Economics 90(4-5), 921–933.

Pindyck, R. S., 2013. Climate change policy: What do the models tell us? Journal of Economic Literature 51(3), 860–872.

Poterba, J. M., 1993. Global warming policy: a public finance perspective. The Journal of Economic Perspectives 7(4), 47–63.

Quadrini, V., Ríos-Rull, J.-V., 1997. Understanding the U.S. distribution of wealth. Federal Reserve Bank of Minneapolis Quarterly Review 21(2), 22–36.

Ramseur, J. L., Leggett, J. A., Sherlock, M. F., 2012. Carbon tax: Deficit reduction and other considerations. Congressional Research Service, report.

Rausch, S., 2013. Fiscal consolidation and climate policy: An overlapping generations perspective. Energy Economics 40, S134–S148.

Rausch, S., Metcalf, G. E., Reilly, J. M., 2011. Distributional impacts of carbon pricing: A general equilibrium approach with micro-data for households. Energy Economics 33, S20–S33.

Rausch, S., Metcalf, G. E., Reilly, J. M., Paltsev, S., 2010. Distributional implications of alternative US greenhouse gas control measures. The BE Journal of Economic Analysis & Policy 10(2).

Reilly, J., Paltsev, S., Strzepek, K., Selin, N. E., Cai, Y., Nam, K.-M., Monier, E., Dutkiewicz, S., Scott, J., Webster, M., Sokolow, A., 2013. Valuing climate impacts in integrated assessment models: the MIT IGSM. Climatic Change 117(3), 561–573.

Rezai, A., Foley, D. K., Taylor, L., 2012. Global warming and economic externalities. Economic Theory 49, 329–531.

Roemer, J. E., 1993. A pragmatic theory of responsibility for the egalitarian planner. Philosophy & Public Affairs 22(2), 146–166.

Roemer, J. E., 2011. The ethics of intertemporal distribution in a warming planet. Environmental and Resource Economics 48(3), 363–390.

Romp, W., De Haan, J., 2007. Public capital and economic growth: A critical survey. Perspektiven der Wirtschaftspolitik 8(S1), 6–52.

Schneider, S. H., 1997. Integrated assessment modeling of global climate change: Transparent rational tool for policy making or opaque screen hiding value-laden assumptions? Environmental Modeling and Assessment 2(4), 229–249.

Schöb, R., 1995. Ökologische Steuersysteme: Umweltökonomie und optimale Besteuerung. Campus.

Schöb, R., 2005. The double dividend hypothesis of environmental taxes: a survey. In: Folmer, H., Tietenberg, T. (Eds.), The international yearbook of environmental and resource economics 2005/2006, pp. 223–279, Edward Elgar.

Schultes, A., Leimbach, M., Edenhofer, O., 2015. Biased climate damages and intergenerational impacts. Mimeo.

Schwartz, J., Repetto, R., 2000. Nonseparable utility and the double dividend debate: Reconsidering the tax-interaction effect. Environmental and Resource Economics 15(2), 149–157.

Shalizi, Z., Lecocq, F., 2010. Climate change and the economics of targeted mitigation in sectors with long-lived capital stock. Policy Research Working Paper No. 5063, The World Bank.

Siegmeier, J., 2016. Keeping Pigou on tracks: second-best combinations of carbon pricing and infrastructure provision. MCC Working Paper Series 2/2016.

Siegmeier, J., Mattauch, L., Edenhofer, O., 2015. Climate policy enhances efficiency: A macroeconomic portfolio effect. CESifo Working Paper No. 5161.

Sims, R., Schaeffer, R., Creutzig, F., Cruz-Nunez, X., D'Agosto, M., Dimitriu, D., Figuera Mez, M. J., Fulton, L., Kobayashi, S., Lah, O., McKinnon, A., Newman, P., Ouyang, M., Schauer, J. J., Sperling, D., Tiwari, G., 2014. Transport. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., Minx, J.-C. (Eds.), Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

Sinclair, P. J., 1992. High does nothing and rising is worse: Carbon taxes should keep falling to cut harmful emissions. The Manchester School 60, 41–52.

Sinn, H.-W., 2008. Public policies against global warming: a supply side approach. International Tax and Public Finance 15(4), 360–394.

Sorrell, S., Sijm, J., 2003. Carbon trading in the policy mix. Oxford Review of Economic Policy 19(3), 420–437.

Staub-Kaminski, I., Zimmer, A., Jakob, M., Marschinski, R., 2014. Climate policy in practice: A typology of obstacles and implications for integrated assessment modeling. Climate Change Economics 05(01), 1440004.

Stern, N. H., 2007. The economics of climate change: the Stern review. Cambridge University Press.

Tahvonen, O., 1995. International CO2 taxation and the dynamics of fossil fuel markets. International Tax and Public Finance 2(2), 261–278.

Thompson, T. M., Rausch, S., Saari, R. K., Selin, N. E., 2014. A systems approach to evaluating the air quality co-benefits of US carbon policies. Nature Climate Change 4, 917–923.

Tol, R. S., Fankhauser, S., 1998. On the representation of impact in integrated assessment models of climate change. Environmental Modeling and Assessment 3, 63–74.

Tullock, G., 1967. Excess benefit. Water Resources Research 3(2), 643–644.

Unruh, G. C., 2000. Understanding carbon lock-in. Energy policy 28(12), 817–830.

Ürge-Vorsatz, D., Herrero, S. T., Dubash, N. K., Lecocq, F., 2014. Measuring the co-benefits of climate change mitigation. Annual Review of Environment and Resources 39(1), 549–582.

von Below, D., Dennig, F., Jaakkola, N., 2013. Consuming more and polluting less today: Intergenerationally efficient climate policy. Mimeo.

von Stechow, C., McCollum, D. L., Riahi, K., Minx, J.-C., Mirasgedis, S., Lah, O., Robledo-Abad, C., Roy, J., Hertwich, E., Jewell, J., 2015. Assessing the diverse literature on integrating global climate change mitigation goals and multiple development objectives. In preparation.

Wagner, R. E. (Ed.), 1991. Charging for Government: User Charges and Earmarked Taxes in Principle and Practice. Routledge, London.

Waisman, H., Guivarch, C., Grazi, F., Hourcade, J. C., 2012. The Imaclim-R model: infrastructures, technical inertia and the costs of low carbon futures under imperfect foresight. Climatic Change 114(1), 101–120.

Weitzman, M. L., 2009. On modeling and interpreting the economics of catastrophic climate change. Review of Economics and Statistics 91(1), 1–19.

West, J. J., Smith, S. J., Silva, R. A., Naik, V., Zhang, Y., Adelman, Z., Fry, M. M., Anenberg, S., Horowitz, L. W., Lamarque, J.-F., 2013. Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health. Nature Climate Change 3(10), 885–889.

Weyant, J., Davidson, O., Dowlabathi, H., Edmonds, J., Grubb, M., Parson, E., Richels, R., Rotmans, J., Shukla, P., Tol, R., Cline, W., Fankhauser, S., 1996. Integrated assessment of climate change: An overview and comparison of approaches and results. In: Bruce, J., Lee, H., Haites, E. (Eds.), Climate Change 1995: Economic and Social Dimensions of Climate Change, pp. 367–439, Cambridge University Press.

Wilkinson, R., Pickett, K., 2009. The Spirit Level: Why Equality is Better for Everyone. Penguin.

Wilson, J. D., 1986. A theory of interregional tax competition. Journal of Urban Economics 19(3), 296–315.

Wilson, J. D., 1999. Theories of tax competition. National Tax Journal 52(2), 269–304.

Wolff, E. N., 1998. Recent trends in the size distribution of household wealth. Journal of Economic Perspectives 12(3), 131–150.

Zodrow, G., 2010. Capital mobility and capital tax competition. National Tax Journal 63, 865–881.

Zodrow, G. R., Mieszkowski, P., 1986. Pigou, Tiebout, property taxation, and the underprovision of local public goods. Journal of Urban Economics 19(3), 356–370.

Part II

Infrastructure and inequality

Chapter 5

Distributional effects of public investment when wealth and classes are back[1]

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Distributional effects of public investment when wealth and classes are back

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Abstract

In developed economies, wealth inequality is high, while public capital is underprovided. Here, we study the impact of heterogeneity in saving behavior and income sources on the distributional effects of public investment. A capital tax is levied to finance productive public capital in an economy with two types of households: high income households who save dynastically and middle income households who save for retirement. We find that inequality is reduced the higher the capital tax rate is and that low tax rates are Pareto-improving. There is no clear-cut trade-off between efficiency and equality: middle income households' consumption is maximal at a capital tax rate that is higher than the rate which maximizes high income households' consumption.

JEL classification: E6, H23, H31, H40, H54

Keywords: Public capital, wealth disparity, inequality, household heterogeneity, Pasinetti Theorem, saving behavior

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1 Introduction

Capital taxation has for a long time not been favored by economists as a revenue-raising option, but has recently received much attention as a means of mitigating inequality in wealth (Piketty, 2014). "Capital is back" (Piketty and Zucman, 2014) as a factor to be taxed for financing public investment in industrialized countries: on the one hand, the capital-output ratio is increasing (Piketty, 2014) which in part explains great wealth disparities (Wolff, 2010). On the other hand, public investment may significantly enhance aggregate productivity (Romp and De Haan, 2007; Bom and Ligthart, 2014). Research on the distributional consequences of public investment has rarely analyzed the impact of distinct financing options. Further, realistic concepts of household heterogeneity in saving motives (Attanasio, 1994; Browning and Lusardi, 1996; Dynan et al., 2004), income sources (Wolff, 1998; Quadrini, 1997; Diaz-Gimenez et al., 2011) and time preference (Lawrance, 1991; Green et al., 1996) should crucially influence the outcome of different financing options for public investment, but previous analyses have neglected such heterogeneity.

This article introduces a model of two stylized types of households to study the effect of financing productive public investment by a capital tax. It answers the following question: is it possible to invest in public capital in a way that all households benefit while the financing mechanism mitigates wealth inequality? The answer is yes when there is significant underprovision of public capital and public investment is financed by a capital tax. We also prove that for each household type a different rate of capital taxation is optimal. These results hold for moderate to high values of the substitution elasticity between capital and labor.

Previous theoretical work on the provision of public capital has focused on homogenous households, not taking into account systematic differences in saving behavior and income. It has emphasized that a trade-off exists between investment into productive public capital and efficiency losses from taxes financing these investments. This trade-off determines an optimal tax rate (Barro, 1990). When household heterogeneity is taken into account to study the effects of public investment on *inequality*, all agents are typically assumed to have identical preferences, while the heterogeneity stems from different initial endowments. For example, Alesina and Rodrik (1994) show that when households differ by the division of their endowment in wealth and (inelastic) labor supply, households with higher labor to capital ratio prefer higher capital taxes. Their model implies that growth is always reduced when the preferred tax rate of all households but those who only hold capital is implemented. When public investment also affects the labor-leisure decision of households, Chatterjee and Turnovsky (2012) find that investing in public capital increases inequality in wealth (and welfare) in the long run, but also growth and average welfare, independent of the financing mechanism.

Here we introduce a two-class model of productive public capital and wealth inequality in which the heterogeneity stems from different saving motives, income sources and time preference rates. There are two different types of households: dynastically-saving high income households, whose only source of income is the interest from their capital stock and middle income households who live for two periods and save out of a life-cycle motive. A capital tax is levied by the government to finance productive public investment. The effect of other revenue sources, such as labor or consumption taxation, and the comparison with capital taxation is treated in our companion paper, Klenert et al. (2016), that extends the present analysis to less stylized functional forms. Our main point in the present article is to prove that capital taxation can both reduce inequality and be Pareto-improving.

Baranzini (1991) was the first to introduce two-class models in which there are capitalists, who leave bequests to their offspring, and workers who save over the life cycle only, thus providing earlier work by Kaldor (1955-1956) and Pasinetti (1962) with micro-foundations. Michl (2007, 2009) presents a version of a two-class model with a dynastically saving capitalist and workers living for two periods, on which our framework builds by modeling saving behavior across classes similarly.[1] We focus on financing public investment, whereas Michl (2009) instead employs a non-marginalist approach to production in order to assess different social security schemes.

In view of rising inequality, there is recently a renewed interest in understanding distributional conflict by means of two-class models: First, Stiglitz (2015a,b) considers a set-up similar to Michl (2009), but with exogenously given saving propensities, to analyze the role of rents for growth and distribution. Second, Dutt (2015) uses a two-class model in which the higher income group also receives wages as managers, in order to study the growth effects of an increasingly skewed distribution between the two classes. He finds that financialization and the increasing incomes of top managers lead to increased inequality and have adverse effects on growth. Third, Ryoo (2015) introduces financial assets and managerial pay into a two-class model and finds, in particular, that a declining growth rate can reduce inequality, in contrast to Piketty (2014). Fourth, Russo (2014) combines the division of the population into capitalists and workers with stochastic explanations for wealth inequality to show how a random process can amplify existing class distinctions.

Our model contains a version of the 'Pasinetti Theorem': In the steady-state the capitalists' propensity to save determines the interest rate (Pasinetti, 1962). We focus on the realistic case of the economy being populated by two classes, neglecting the "dual-Pasinetti equilibrium" of middle income households owning all capital (Samuelson and Modigliani, 1966), which is widely considered irrelevant (Pasinetti, 1966, 1974).[2] Given the empirical evidence summarized by Piketty (2014), one may rather wonder whether the 'anti-dual outcome', that high income households own all capital, is a real possibility (Taylor, 2014; Zamparelli, 2015).

To the best of our knowledge, Steedman (1972) was the first to examine how government activity influences the Pasinetti result, while La Marca (2005) more recently provided a synthesis of how government activity leads to the different possible equilibria. The case of the government providing productive public investment has, however, not been considered in the Post Keynesian strand of literature, but is otherwise standard (Barro, 1990; Futagami et al., 1993; Turnovsky, 1997). Recently, Tavani and Zamparelli (2015) study productive

[1] Michl and Foley (2004) and Michl (2009) label the two classes 'capitalists' and 'workers' respectively. We prefer to label these classes 'high income households' and 'middle income households' instead, because recent data (Wolff, 2010) suggests the existence of a third class, which hardly saves anything in some countries, see below. We believe that the term 'worker' is rather associated with such a third class.

[2] See Pasinetti (2012) for reflections from a contemporary perspective and implications for the current economic situation.

public capital also in a *classical* setting with a division between workers, who own no capital, and capital holders. They find that government action should differ according to the different growth model closures of elastic labor supply at a given wage share or fixed labor supply with adjusting real wage. Depending on the different closures, the government may be able to alleviate distributional conflicts by taxing profits to finance public investment and to provide transfers to workers.

In this article, we prove the following results: first, the higher the capital tax rate, the higher the share of capital owned by the middle income households, thus mitigating inequality in wealth. This result is due to the different saving motives of the two household types and hence the Pasinetti property of our model. Second, there is not one optimal level of capital taxation, but each type of household desires a different level. Middle income households are more favorable to the investment in public capital and desire a higher capital tax rate than high income households. The reason is that middle income households' savings depend only on their labor income. These first two results are reversed for low values of the substitution elasticity between capital and labor. Third, a Pareto-improving capital tax rate exists nevertheless: it can be proved that if public capital is underprovided, both classes are made better off as long as public capital is not unreasonably productive. The results together imply that there is no clear trade-off between equity and efficiency.

The division of households into two types with respect to their saving behavior is highlighted by recent data on wealth ownership. For example Wolff (2010) finds for the U.S. that the wealthiest 5 % of the population own roughly 62 % of total wealth, the next 55 % of the population own close to the remaining 38 %, while the rest of the population owns virtually no wealth. What distinguishes these cohorts? An analysis of the literature yields three major characteristics. First, the saving motive: The wealthiest cohort has been found to save dynastically, while the middle part of the wealth distribution is known to save in a life-cycle fashion (Attanasio, 1994; Browning and Lusardi, 1996; Dynan et al., 2004). Second, the income source: The wealthiest individuals are more likely to be self-employed entrepreneurs and to receive a higher share of capital income (Wolff, 1998; Quadrini, 1997; Diaz-Gimenez et al., 2011; Wolff and Zacharias).[3] Third, lower income households have higher time preference rates, as shown by Lawrance (1991) and Green et al. (1996). These empirical findings suggest dividing households into three groups with distinctly different saving motives: The wealthiest income cohorts are mainly self-employed and save dynastically, which suggests that they should be modeled as infinitely-lived households who only receive capital income. The cohorts in the middle of the wealth distribution save mainly for their retirement and are thus best represented as overlapping generation agents that have income from both labor and capital. The poorest households do not save. They are excluded from our analysis as the benefits they may derive from public investment are unlikely to affect their saving behavior.[4]

[3]According to Wolff (1998) 72 percent of the richest 1% were self-employed entrepreneurs for data on U.S. households for 1995.

[4]Their welfare may still be affected through an effect on wages, but this is not the focus of the present article. Our analysis of Pareto-improving policies seems valid even when including this cohort because the wage effect is likely to be positive, see the discussion of our results in Section 3.

Finally, evidence indicates that public investment is indeed suboptimally low in OECD countries. Building on Aschauer (1989) and Gramlich (1994), Bom and Ligthart (2014) recently conducted a meta-analysis: the output elasticity of public capital is estimated to be between 0.08 and 0.19, with short-run effects and a broad definition of public capital giving the lower bound. The higher estimate is reached for the long run and particularly for transport infrastructure and utilities at the regional level. It follows that public capital is underprovided because its corresponding marginal productivity is (significantly) higher than that of private capital.

The remainder of this article is structured as follows: Section 2 sets out the model. Section 3 first presents its steady-state properties and then contains the proofs of the main results. Further subsections subsequently elucidate the role of the elasticity of substitution between labor and capital as well as the robustness of our modeling assumptions about public capital, partially by means of numerical solutions. Section 4 summarizes the results and considers possible extensions.

2 Model

We model a one-good economy in which the government can finance public capital that enhances productivity. The population consists of two classes, high income households and middle income households. The representative middle income household provides labor when its members are young and they save for retirement; the household leaves no bequests. Middle income households are modeled as members of overlapping generations. The representative high income household holds capital and interest is its sole source of income. It has a dynastic saving motive and is thus modeled as an infinitely-lived agent. Both types of agents derive utility from consumption only. Factor markets clear and on the capital market, the supply consists of both high income households' investment and middle income households' savings. There are decreasing returns to scale in private and public capital, but constant returns to scale in private capital and labor. We first describe the households' behavior before detailing the role of the firms and the government.

High income household The high income household owns a capital stock K_t^c and maximizes intertemporal utility given by

$$\sum_{t=0}^{\infty} \frac{1}{(1+\rho_c)^t} \ln(C_t^c), \tag{1}$$

with consumption C_t^c and time preference rate ρ_c. Its budget constraint is

$$K_{t+1}^c - K_t^c = (1-\tau) r_t K_t^c - C_t^c, \tag{2}$$

where r_t is the interest rate and τ is the capital tax.

The initial capital stock is given as $K_1^c = K_0^c$. The high income household respects a transversality condition: $\lim_{t\to\infty}\left(K_t^c \prod_{s=1}^{t-1} \frac{1}{1+r_s}\right) \geq 0$.

Solving the maximization problem yields an Euler equation for this household:

$$\frac{C_{t+1}^c}{C_t^c} = \frac{1+(1-\tau)r_{t+1}}{1+\rho_c}. \tag{3}$$

Middle income household The middle income household lives for two periods, a 'young' (y) and an 'old' (o) stage. It maximizes its lifetime utility, where utility from consumption in the second period is discounted by the time preference rate ρ_w:

$$\ln(C_t^y) + \frac{1}{1+\rho_w}\ln(C_{t+1}^o). \tag{4}$$

In the first period, the middle income household rents its fixed labor L to the producing firm, which in turn pays a wage rate w_t. Labor income can either be consumed or saved for the old age:

$$w_t L = S_t + C_t^y. \tag{5}$$

In the second period the middle income household consumes its savings and the interest on them:

$$C_{t+1}^o = (1+(1-\tau)r_{t+1})S_t. \tag{6}$$

Solving the optimization problem subject to the budget constraints leads to an Euler equation for this household:

$$\frac{C_{t+1}^o}{C_t^y} = \frac{1+(1-\tau)\cdot r_{t+1}}{1+\rho_w}. \tag{7}$$

From Equations (5-7) explicit expressions for saving and consumption in the two periods can be derived:

$$S_t = \frac{1}{2+\rho_w}w_t L \tag{8}$$

$$C_t^y = \left(\frac{1+\rho_w}{2+\rho_w}\right)w_t L \tag{9}$$

$$C_{t+1}^o = \left(\frac{1+(1-\tau)r_{t+1}}{2+\rho_w}\right)w_t L. \tag{10}$$

The savings rate is constant, as is standard in discrete OLG models when the utility function is logarithmic. The same is true for the consumption of the young agent, while C_{t+1}^o is still dependent on the interest rate r. Moreover, combining Equations (8-10) implies that C_t^y and C_{t+1}^o depend linearly on savings S.

Production The firm produces output according to a Cobb-Douglas production function. Public capital P_t enhances productivity of both factors:

$$F(K_t, L) = A_t K_t^{\alpha} L^{1-\alpha} \tag{11}$$

with $A_t = P_t^{\beta}$, and $0 < \alpha, \beta < 1$. So β denotes the efficiency factor of public capital P_t. Throughout, we assume $\alpha + \beta < 1$ to exclude the case of long-run or explosive growth.

K_t denotes the sum of the individual capital stocks

$$K_t = K_t^c + S_{t-1}. \tag{12}$$

Profit maximization yields the standard rates of return for capital and labor (with δ_K denoting depreciation of private capital):

$$r_t + \delta_K = \frac{\partial F(K_t, L)}{\partial K_t} = \alpha\frac{F(K_t, L)}{K_t} \tag{13}$$

$$w_t = \frac{\partial F(K_t, L)}{\partial L} = (1 - \alpha)\frac{F(K_t, L)}{L}. \tag{14}$$

Government The sole function of the government in this model is the provision of public capital. It finances its investments by the capital tax, thus influencing the interest rate. Hence the government's activity is summarized as the change in the stock of public capital (with δ_P denoting its depreciation):

$$P_{t+1} = P_M + (1 - \delta_P)P_t + \tau r_t K_t. \tag{15}$$

For the following analytical results, we assume that for non-governmental provision of public capital P_M,

$$P_M = 0. \tag{16}$$

One could object to such a stylized role for public capital in our model that the finding of Pareto-improving public investment relies on very high marginal returns to public capital if public investment approaches zero. We address this concern by confirming numerically (in Subsection 3.3) that even if a minimal provision of public good $P_M > 0$ is present without government intervention our qualitative results do not change.

3 Results

In this section we show that inequality in wealth is mitigated by a capital tax levied for public investment in our model. We also characterize the optimal tax rate for each household type: the middle income household is more favorable to capital taxation and higher public investment than the high income household. We point out that low capital tax rates lead to a Pareto improvement, even for the case in which the economy is functioning without any public investment. Figures 1 and 2 below illustrate the main findings. First, we characterize the steady-state and the validity range of the model. We then prove the results just stated for the case of a Cobb-Douglas production function. Further, the model is calibrated and analyzed numerically to determine the optimal tax rates, which cannot be calculated explicitly and to examine the role of potential non-publicly provided existing infrastructure. The numerical analysis also ensures that all critical values for the tax rate are within the validity limit of the two-class model for a wide range of parameters. Finally, we generalize the analysis to a wider range of elasticities of substitution between capital and labor.

3.1 Steady state and validity range

In our model, a version of the Pasinetti Theorem holds. In a model with two types of households, in which one household only receives income from capital – the "capitalist" –, the Pasinetti Theorem (Pasinetti, 1962) states that the capitalist will determine the steady state interest rate independently of the saving rate of the other household type – the "worker" – or the production technology. This is true unless the worker's saving propensity is so high that the capitalist class ceases to exist (Samuelson and Modigliani, 1966).

In the steady-state of our model we find a similar duality although the saving behavior of our household types is derived from their intertemporal preferences: Either (i) the high income household (corresponding to the "capitalist") determines the steady-state interest rate *or* (ii) its capital stock and consumption is zero and the economy is populated only by the middle income household (corresponding to the "worker"). Which regime holds in the steady-state of our model depends on its parameters. In the following analysis, we are exclusively concerned with (the applicable) case (i) (Pasinetti, 1966, 2012). We study the effect of the capital tax on the wealth distribution and call the tax rate at which the high income household's share of capital approaches zero, the limit of case (i), the model's validity limit.

The (unique, non-trivial) steady-state is saddle-point stable and the economy converges to it on a stable path because the high income household's behavior determines the overall dynamics.[5] The Pasinetti-type behavior of the model in the steady-state can be explained as follows: The high income household's saving behavior determines the interest rate because reducing or increasing its investment is its only means of obtaining its desired long-term distribution of consumption to capital, as is also true in a standard Ramsey model. Any attempt of the middle income household to obtain a different interest rate would thus be balanced by the high income household adjusting its saving rate. Thus the middle income household accepts the interest rate as given. However, its propensity to save (which is independent of the interest rate) influences the amount the high income household saves, who is bound to own the share of total capital net of what the middle income household saves. Thus the high income household determines the interest rate and with it the total capital stock, but the middle income household determines the capital share owned by the high income household.

Steady-state values of variables are denoted by a tilde. We first assume that the high income household's consumption is strictly positive, $\widetilde{C^c} > 0$ and then derive the validity range of this assumption.

It follows from the high income household's Euler Equation (3) that

$$\widetilde{r} = \frac{\rho_c}{(1-\tau)} \tag{17}$$

and from its budget constraint (2) that

$$\widetilde{C^c} = \rho_c \widetilde{K^c}. \tag{18}$$

The steady-state level of public capital is given by:

$$\widetilde{P} = \frac{1}{\delta_P} \tau \widetilde{r} \widetilde{K}. \tag{19}$$

[5] A heuristic argument for saddle-point stability is as follows: The dynamics of the model are captured by four Equations for the variables K^c, C^c, P and K, namely Equations (2), (3), (15) and substituting Equation (8) into Equation (12). If it were the case that $K^c = K$, then the model would be a neoclassical growth model with public capital in discrete time. The dynamics of public capital is such that the required stability properties carry over from the neoclassical growth model, where C^c is a "jump variable". What does Equation (12) add to the dynamics of the case $K^c = K$? The only modification is that in Equations (2) and (3) the interest rate is lower than if K^c was the only capital input (the revenue in Equation (8) stays a constant fraction of total output). This implies that there are no qualitative differences in the dynamics, only the steady-state value of K^c is smaller than the Keynes-Ramsey level of capital K by exactly S. This can be shown by transforming the original system by dividing all variables through Y, and noting that $\frac{K}{Y} = \frac{K^c}{Y} - \frac{1-\alpha}{1+\rho_c}$, which reduces the transformed system to three dimensions.

For later reference only, we note that in the steady-state an explicit expression for $\widetilde{K}$ can be obtained. From Equation (13) a steady-state relationship for the production factors $\widetilde{P}$ and $\widetilde{K}$ can be derived:

$$\alpha \widetilde{P}^{\beta} \widetilde{K}^{\alpha-1} L^{1-\alpha} = \frac{\rho_c}{1-\tau} + \delta_k. \tag{20}$$

Rearranging and inserting Equation (19) into Equation (20) gives an explicit expression for $\widetilde{K}$:

$$\widetilde{K}^{(1-\left(\frac{\beta}{1-\alpha}\right))} = L\left(\tau \frac{\rho_c}{\delta_P(1-\tau)}\right)^{\left(\frac{\beta}{1-\alpha}\right)} \left(\frac{\frac{\rho_c}{(1-\tau)} + \delta_k}{\alpha}\right)^{\left(-\frac{1}{1-\alpha}\right)}. \tag{21}$$

The equation shows that K as a function of τ is inverted U-shaped (recalling from above that we exclude the case $\beta > 1-\alpha$). This is because of two counteracting effects: as τ increases, K initially increases due to the productivity-enhancing effect of public capital (given by the first term of the product). However, it eventually decreases because of the distortionary effect of capital taxation that discourages capital accumulation (represented by the second term above).

Validity limit The above equations (17–21) are only valid if both agents have positive capital and consumption (see the discussion at the beginning of this section). This is ensured as long as the middle income household's savings are smaller than the total capital, that is

$$\frac{\widetilde{S}}{\widetilde{K}} = \frac{L\widetilde{w}}{(2+\rho_w)\widetilde{K}} = \frac{(1-\alpha)}{\alpha(2+\rho_w)}\left(\frac{\rho_c}{1-\tau} + \delta_k\right) < 1, \tag{22}$$

where Equations (8) , (14) and (20) were used to obtain an expression in terms of parameters only. We use the ratio $\frac{\widetilde{S}}{\widetilde{K}}$, the share of capital held by the high income household, as an indicator for wealth inequality below.

From Equation (22), one can derive that there exists a constant $\tau_{lim} < 1$ for which the steady-state characterization of the agents' behavior is valid in exactly the interval $(0;\tau_{lim})$. The expression of τ_{lim} is:

$$\tau_{lim} = 1 - \rho_c\left(\frac{1-\alpha}{\alpha(2+\rho_w) - \delta_k(1-\alpha)}\right). \tag{23}$$

For the remainder of the analysis, we assume that all critical values of τ are within the interval on which the analysis is valid. We check numerically in Section 3.3 that this assumption holds for a wide range of parameters, including those that best represent developed economies in a stylized way.

We next describe the impact of the capital tax rate on the steady-state behavior.

3.2 The effects of policy

The three main results regarding the role of fiscal policy in our model are stated as three propositions below:

- a capital tax levied for public investment decreases inequality in wealth (Proposition 1),

- middle income households prefer a higher capital tax rate than high income households (Proposition 2) and
- there exists a Pareto-improving range of capital tax rates (Proposition 3).

Below, inequality and optimality for the two household types are exclusively discussed in terms of their *wealth*: This is sufficient as the *consumption* of the high income household and the old and young middle income household are linear functions of their wealth. For the case of the high income household this is due to Equation (18), for middle income household's consumption it is an immediate consequence of Equations (8–10).

The economic intuition behind the three propositions can be developed as follows: The first result is a consequence of the Pasinetti Theorem. The middle income household's savings are proportional to its wage income, which is proportional to total output. So the share of the middle income household's savings to total capital – the indicator for inequality – depends linearly on the ratio of total output to total capital. By the properties of the neoclassical production function, the output-capital ratio depends positively on the marginal productivity of capital. However, the marginal productivity of capital increases for higher capital taxes, even independently of how the tax revenue is used. This follows from the Pasinetti-behavior of the model – as the interest rate is fixed by the high income household's behavior to be an increasing function of the tax rate (see Equation (17)).

The second result is derived from the fact that total capital depends in a convex way on the capital tax. The relationship is determined by the counteracting effects of the distortion through the capital tax and the beneficial effect of spending it on public investment that also impacts the productivity of private capital positively.[6] The maximal wealth of the middle income household then occurs for a higher capital tax value because his savings depend *only* on his labor income. His labor income depends monotonically on accumulated total private capital, but also on public capital, and the impact of the latter is always positive. The maximal wealth of the high income household occurs for lower capital values as a consequence of the first result: The share of total capital belonging to the middle income household increases faster than total capital the higher the capital tax. Hence the maximal share of the high income household must be reached for lower values of the capital tax than the maximal total capital.

The third result is due to the fact that the marginal productivity of public capital is higher than the efficiency loss from distortionary capital taxation, if little public capital is provided. Section 3.3 provides a numerical analysis of the magnitude of this effect: The possibility that some public capital may exist even if there is no government intervention is considered there, but it is found that the level of non-government financed public capital would need to be very high to rule out the possibility of a Pareto improvement.

Figures 1 and 2 illustrate these results.

Proposition 1. *Capital taxation (used for public investment) decreases inequality in wealth:* $\frac{\mathrm{d}(\frac{\tilde{S}}{\tilde{K}})}{\mathrm{d}\tau} > 0$ *for* $0 < \tau < 1$.

[6]This is the same trade-off between efficiency-enhancing public investment and distortionary capital taxation studied by Barro (1990) for a single infinitely-lived agent.

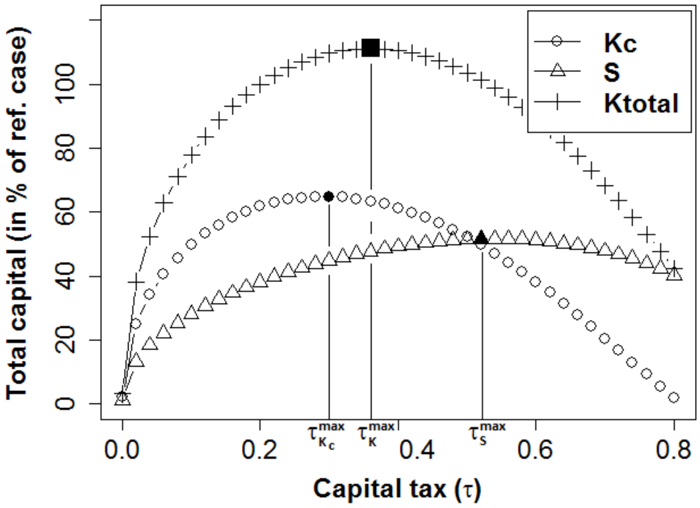


Figure 1: The graph shows the size of the different private capital stocks for capital taxes between 0 and $\tau_{lim} = 81\%$. Each capital stock has its maximum for a different value of the capital tax τ. The high income household prefers a lower tax rate than the middle income household, with the capital tax rate that maximizes total capital in between (i.e. $\tau_{K_c}^{max} < \tau_K^{max} < \tau_S^{max}$). Units of capital are normalized to 100% at the reference case of $\tau = 21\%$.

Proof. From Equation (22),

$$\frac{\widetilde{S}}{\widetilde{K}} = \frac{(1-\alpha)}{\alpha(2+\rho_w)}\left(\frac{\rho_c}{1-\tau} + \delta_k\right), \tag{24}$$

which is increasing in τ. □

Proposition 2. *Middle income households prefer a higher capital tax rate than high income households: for some threshold rate* τ^*, $\frac{\mathrm{d}\widetilde{S}(\tau)}{\mathrm{d}\tau} > 0$ *for* $0 < \tau < \tau^* + \varepsilon$ *and* $\frac{\mathrm{d}\widetilde{K}^C(\tau)}{\mathrm{d}\tau} < 0$ *for* $1 > \tau > \tau^* - \varepsilon$ *for some* $\varepsilon > 0$.

Proof. Let τ^* be the value of τ that maximizes $\widetilde{K}$ as a function of τ on $(0,1)$: it can be calculated that for $\tau^* = \frac{\beta(\rho_c+\delta_k)}{\beta\delta_k+\rho_c}$, $\frac{\mathrm{d}\widetilde{K}(\tau^*)}{\mathrm{d}\tau} = 0$ and shown that $\frac{\mathrm{d}\widetilde{K}(\tau)}{\mathrm{d}\tau} > 0$ for $\tau < \tau^*$ and $\frac{\mathrm{d}\widetilde{K}(\tau)}{\mathrm{d}\tau} < 0$ for $\tau > \tau^*$ (see Supplementary Material, available from the authors upon request).

By combining Equations (8), (14) and (19), we obtain:

$$\widetilde{S} = \underbrace{\frac{1-\alpha}{2+\rho_w} L^{(1-\alpha)} \left(\frac{\rho_c}{\delta_P}\right)^{\beta}}_{=\vartheta} \left(\frac{\tau}{(1-\tau)}\right)^{\beta} \widetilde{K}^{\alpha+\beta}.$$

Thus:

$$\frac{\partial\widetilde{S}}{\partial\tau} = \vartheta\left(\frac{\tau}{1-\tau}\right)^{\beta}\left[\frac{\beta}{\tau(1-\tau)} + \frac{\alpha+\beta}{\widetilde{K}}\frac{\partial\widetilde{K}}{\partial\tau}\right]\widetilde{K}^{\alpha+\beta}. \tag{25}$$

Hence $\frac{\mathrm{d}S(\tau)}{\mathrm{d}\tau} > 0$ for $0 < \tau < \tau^*$. Also $\frac{\mathrm{d}S(\tau)}{\mathrm{d}\tau}$ is continuous and strictly positive at τ^*, thus positive on $[\tau^*, \tau^* + \varepsilon]$ for some ε.

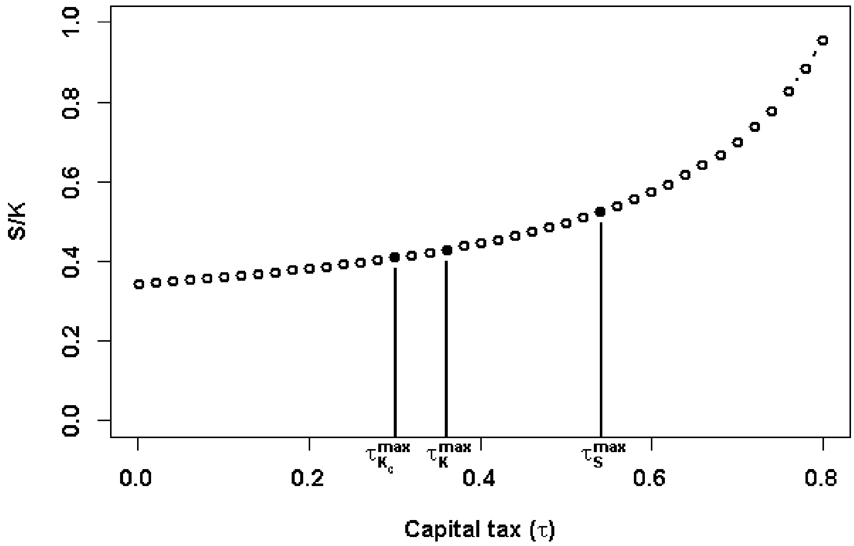


Figure 2: This graph illustrates Proposition 1: the middle income household's share of total capital increases within the validity range of capital taxes between 0 and $\tau_{lim} = 81\%$.

For a similar argument for $\widetilde{K}^C$, use that

$$\widetilde{K}^C = \widetilde{K}(1 - \frac{\widetilde{S}}{\widetilde{K}}).$$

For $1 > \tau > \tau^*$, $\widetilde{K}^C$ is thus the product of two positive decreasing functions and hence $\frac{\mathrm{d}\widetilde{K}^C(\tau)}{\mathrm{d}\tau} < 0$ there. At τ^*, $\frac{\mathrm{d}\widetilde{K}^C(\tau)}{\mathrm{d}\tau}$ is strictly negative and continuous, hence it is also negative on $[\tau^* - \varepsilon, \tau^*]$. □

Proposition 3. *If* $2\beta < 1 - \alpha$, *there exists a Pareto-improving range of capital tax rates:* $\frac{\mathrm{d}\widetilde{S}(\tau)}{\mathrm{d}\tau} > 0$, $\frac{\mathrm{d}\widetilde{K}^C(\tau)}{\mathrm{d}\tau} > 0$ *for small* $\tau > 0$.

Proof. From Equation (25), $\frac{\mathrm{d}\widetilde{S}(\tau)}{\mathrm{d}\tau} > 0$ is positive, if $\frac{\mathrm{d}\widetilde{K}(\tau)}{\mathrm{d}\tau} > 0$ is, which is true for all $0 < \tau < \tau^*$.

For $\widetilde{K}^C = \widetilde{K}(1 - \frac{\widetilde{S}}{\widetilde{K}})$, it is sufficient to prove that $\lim_{\tau\to 0} \frac{\mathrm{d}\widetilde{K}(\tau)}{\mathrm{d}\tau} > 0$, because

$$\frac{\mathrm{d}\widetilde{K}^C(\tau)}{\mathrm{d}\tau} = \frac{\mathrm{d}\widetilde{K}(\tau)}{\mathrm{d}\tau}(1 - \frac{\widetilde{S}}{\widetilde{K}}) + \widetilde{K}\frac{\mathrm{d}}{\mathrm{d}\tau}(1 - \frac{S}{K}) \tag{26}$$

and the second summand goes to zero by Equation (24) as well as noting $\lim_{\tau\to 0} \widetilde{K}(\tau)$. It can be shown that

$$\lim_{\tau\to 0} \frac{\mathrm{d}\widetilde{K}(\tau)}{\mathrm{d}\tau} = \begin{cases} \infty & \text{if } 2\beta < 1 - \alpha, \\ 0 & \text{if } 2\beta > 1 - \alpha. \end{cases} \tag{27}$$

(See the Supplementary Material for the derivation of this claim). □

In the following subsection we verify numerically that the proposition also holds for $\beta > \frac{1}{2}(1-\alpha)$. Empirically, with current estimates of $\beta = 0.2$ and $\alpha = 0.38$ (see page 14 below), the parameter restriction needed here to obtain the analytical result is rather harmless.

3.3 Calibration and robustness with respect to modeling public capital

In the derivation of the three propositions above, we assumed that there is no public capital when there are no taxes levied to finance it ($P_M = 0$). This implies a very high, potentially implausible, marginal productivity of public capital when very little of it is provided. To relax this assumption (needed for analytical tractability above), we present results from a numerical simulation as a robustness check, in which it is assumed that some public capital is provided even without government intervention. We also determine the tax values which cannot be calculated analytically, such as $\tau_{k_c}^{max}$ and τ_s^{max} and list the corresponding values for the distribution of capital between the agents $\frac{S}{K}$. We finally determine the range of each input parameter, within which the validity condition (23) from Section 3.1 holds: outside the validity range, the model is not meaningful because only one class would exist. Table 2 gives the broad range of parameters in which the model is within the validity limit.

The simulation yields that the results of Propositions 1–3 also hold for low to moderate base levels of the public capital stock and illustrates the dependency of optimal tax rates on different public capital productivities β. The results are summed up in Table 1. The corresponding figures show the trajectories of capital K, K^C and S and consumption C (Figure 1) and of capital ownership $\frac{S}{K}$ (Figure 2) for tax rates between 0 and $\tau_{lim} = 0.81$. Values of the stocks displayed are steady-state values without indicating this by a tilde in this subsection.

Parameter	$\tau_{k_c}^{max}$	τ_k^{max}	τ_s^{max}	$\frac{S}{K}\vert\tau_{k_c}^{max}$	$\frac{S}{K}\vert\tau_k^{max}$	$\frac{S}{K}\vert\tau_S^{max}$
$\beta^1 = 0$	0	0	0	0.34	0.34	0.34
$\beta^2 = 0.1$	0.16	0.2	0.37	0.37	0.38	0.43
$\beta^3 = 0.2$	0.29	0.36	0.54	0.41	0.43	0.53
$\beta^4 = 0.3$	0.41	0.49	0.64	0.45	0.49	0.62
$\beta^5 = 0.4$	0.52	0.60	0.70	0.51	0.57	0.71
$\beta^6 = 0.5$	0.63	0.69	0.75	0.60	0.68	0.80
$P_M^1 = 0$	0.29	0.36	0.54	0.41	0.43	0.53
$P_M^2 = 4$	0.14	0.24	0.48	0.37	0.39	0.48
$P_M^3 = 8$	0	0.12	0.44	0.34	0.36	0.46
$P_M^4 = 12$	0	0	0.40	0.34	0.34	0.45

Table 1: Numerical results for varied public capital parameters β and P_M. The table displays the capital tax values which maximize the different capital stocks and the ratio of middle income household's savings to total capital for these tax rates. The highlighted rows correspond to the standard calibration, see Table (2) for the other parameter values. Units of P_0 can be converted to units of the private capital stock K as follows: $P_M = 4$ corresponds to $P_M \approx 21\%$ of the steady-state value of K in the baseline calibration.

The non-highlighted rows in Table (1) show the results for varied public capital productivity (β), and varied initial public capital stock (P_M), displaying the change in the numerical values for τ and $\frac{S}{K}$. The main results remain true up to a base level of public capital of $P_M < 8$ (corresponding to $\approx 21\%$ of the steady-state value of K in the baseline calibration). For values $P_M \geq 8$, no Pareto improving policy is possible anymore as further public investment is of no value to the high income household, who prefers a tax rate of 0. For the case of totally unproductive public capital ($\beta = 0$) each agent prefers a tax rate of 0.

A more extensive sensitivity analysis of all parameters of the model shows that for the ranges given in Table (2), the results obtained with the standard calibration are robust. In particular all capital stocks as functions of the capital tax rate reach their maximum within the model's validity limit for a large parameter range.

We calibrated the model so that for a capital tax of 21 %, which is the average capital tax rate in OECD countries between the years 1970 and 2000 (Carey and Rabesona, 2002), the distribution of wealth is as in Wolff (2010): in the U.S. in 2007, 62 % of net worth are held by the top 5 % of the population and almost 38 % of net worth by the next 55 % (while the bottom 40 % hardly possess any net worth). In accordance with findings on significant differences in intertemporal behavior of different income cohorts, the time preference rate of high income households is chosen lower than that of middle income households (Lawrance, 1991; Green et al., 1996).

The capital's share of income α in the production function was chosen to be 0.38. This is in accordance with observations by the OECD, that in 26 OECD countries with reliable data available, the labor share of income was dropping from 66.1 % to 61.7 % from 1990 to 2009 (OECD, 2012). The productivity of public capital β, which is varied above to highlight the robustness of the result, has been estimated to be between 0.08 and 0.19 (Bom and Ligthart, 2014), downwardly correcting higher estimates from earlier studies (Aschauer, 1989; Gramlich, 1994). Labor L, the total working hours, is a fixed factor in our model. Its value scales all variables.[7] We normalize labor $L = 100$ and measure the other variables in this unit to obtain values in a convenient range. Time is measured in steps of 30 years, as middle income households are assumed to live for two periods.

3.4 The role of the elasticity of substitution between capital and labor

The above results are proved for the case of a Cobb-Douglas production function (see Equation 11), implying an elasticity of substitution of capital and labor $\sigma = 1$. In this subsection we relax this assumption to show that the first two results of the article depend on the value of σ. Its empirical value has recently been debated: For instance, a meta-study finds that "the weight of the evidence suggests a value of σ in the range of 0.40 to 0.60" (Chirinko, 2008) with 26 out of 31 studies finding an elasticity below 1 (see also Rognlie, 2014). This would imply that a Cobb-Douglas production function is not a good approximation to reality. In contrast and more recently, Piketty and Saez (2014) and Piketty and

[7]This can be seen from Equations (8), (9) and (10) for the overlapping generations household, from Equation (18) and (21) for the infinitely-lived household and Equation (19) for public capital.

Parameter	Range	Standard value	Corresponding annual value
ρ_c	0.2 – 1.6	0.56	1.5%
ρ_w	3.0 – 8.0	3.98	5.5%
δ_k	0.3 – 1.7	0.7	4%
δ_P	0.3 – 3.1	0.7	4%
β	0.0 – 0.5	0.2	–
P_M	0.0 – 5.0	0.0	–

Table 2: For values inside the range given in column two, the results of the model are economically meaningful: that is, the functions $K(\tau)$ and $S(\tau)$ reach their maximum within the validity range ($0 < \tau < \tau^{lim}$). In the third and fourth column the standard values used in the simulation and the corresponding yearly values are given.

Zucman (2015) argue, based on the data on changes in the capital-output ratio collected in Piketty and Zucman (2014), that the elasticity must be higher than 1. It is thus vital to understand how the above results change if an elasticity unequal to 1 is considered.

We show below that for elasticities significantly lower than 1, there is an additional effect that determines the level of inequality when public capital is financed by a capital tax: wealth inequality can also be rising because, for fairly inelastic production factors, a capital tax harms wages more than capital. Below, we first prove that wealth inequality could also *increase* for low elasticities and high capital tax rates or for all capital tax rates and very low elasticities. We subsequently determine numerically for which values this happens: under our standard parametrization (see Subsection 3.3) we find that: (i) inequality is unambiguously decreasing for all values of $\sigma > 0.82$, (ii) it is declining for low tax values and then rising for high tax values for $0.61 < \sigma \leq 0.82$. and (iii) inequality is rising for $\sigma \leq 0.61$.

To obtain these results, let production be given by

$$F(K_t, L) = \left(\alpha K^\gamma + (1-\alpha)(AL)^\gamma\right)^{\frac{1}{\gamma}} \tag{28}$$

with $A = P^\beta, P_M = 0, \gamma < 1, \gamma \neq 0$.

This implies that the elasticity of substitution between capital and labor σ is given by $\sigma = \frac{1}{1-\gamma}$. For this particular CES-production function, an explicit expression for the steady-state capital share of middle income households $\frac{\widetilde{S}}{\widetilde{K}}$ can still be derived (derivation in the Supplementary Material):

$$\frac{\widetilde{S}}{\widetilde{K}} = \frac{(1-\alpha)}{\alpha(2+\rho_w)}\left(\frac{\rho_c}{1-\tau} + \delta_k\right) \times \left(\frac{1}{(1-\alpha)}\left(\left(\frac{1}{\alpha}\left(\frac{\rho_c}{1-\tau} + \delta_k\right)\right)^{\frac{\gamma}{(1-\gamma)}} - \alpha\right)\right). \tag{29}$$

It can further be shown that the function $\frac{\widetilde{S}}{\widetilde{K}}(\tau)$ has a maximum at:

$$\tau_z = 1 - \frac{\rho_c}{\alpha(\alpha(1-\gamma))^{\frac{1-\gamma}{\gamma}} - \delta_K}. \tag{30}$$

For the relevant parameter range, the derivative is positive for $\tau < \tau_z$ and negative for $\tau > \tau_z$ (see Supplementary Material): $\frac{\widetilde{S}}{\widetilde{K}}(\tau)$ has exactly one maximum at τ_z, which is in the economically relevant range of $\tau \in (0,1)$ for specific values of γ only.

This finding gives rise to different cases: If $\tau_z < 0$, or $\tau_z > 1$, wealth inequality will increase or decrease monotonically, respectively. Further, the maximum of the function $\frac{\widetilde{S}}{\widetilde{K}}(\tau)$ matters only for the economic outcome if it is within the validity limit of the model, which is now dependent on γ, as it is determined by $\frac{\widetilde{S}}{\widetilde{K}}(\gamma) < 1$. If the maximum occurs within this range, inequality will decrease for tax values lower than this maximum and increase for tax values higher than it. If instead the maximum occurs for $\tau_z \in (0,1)$ but yields $\frac{\widetilde{S}}{\widetilde{K}}(\tau_z) > 1$, inequality is decreasing for all (meaningful) tax rates. We verify numerically below that all these cases occur and that they monotonically depend on γ.

We next determine the specific cases for γ for which the limiting cases (that is, $\frac{\widetilde{S}}{\widetilde{K}}(\tau_z)$=0 and $\frac{\widetilde{S}}{\widetilde{K}}(\tau_z)$=1) occur. First, set $\tau = 0$ in Equation (30) and solve for γ. This yields:

$$(\frac{1}{\alpha}(\rho_c + \delta_K)) = (\alpha(1-\gamma_0))^{\frac{1-\gamma_0}{\gamma_0}} \tag{31}$$

Second, to find out for which γ, $\frac{\widetilde{S}}{\widetilde{K}}(\tau_z) = 1$, it can be verified that

$$\frac{\widetilde{S}}{\widetilde{K}}(\tau_z) = -\frac{\alpha\gamma_1}{(2+\rho_w)}\big(\alpha(1-\gamma_1)\big)^{\frac{1-\gamma_1}{\gamma_1}}. \tag{32}$$

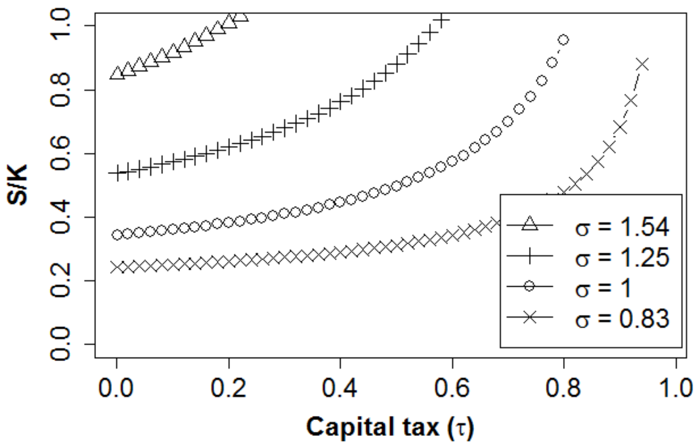
Setting this equal to 1 leads to:

$$(-\frac{2+\rho_w}{\alpha\gamma_1})^{\frac{\gamma}{1-\gamma_1}} = \alpha(1-\gamma_1). \tag{33}$$

Equations (31) and (33) are not generally solvable analytically for γ. We instead solve these equations numerically: solutions for γ_0 and γ_1 and the corresponding elasticities σ_0 and σ_1, depending on α for robustness, are given in Table 3. Further, Figure 3 illustrates the behavior of $\frac{\widetilde{S}}{\widetilde{K}}(\tau)$ for key values of the elasticity. Table 4 then presents how the preferred tax rates of the two cohorts depend on it. It illustrates that public investment is still Pareto-improving for any elasticity, but that middle income households may prefer lower capital taxes for low elasticities.

α	γ_0	σ_0	γ_1	σ_1
0.2	-1	0.5	- 0.42	0.7
0.3	-0.78	0.56	-0.29	0.78
0.38	-0.645	0.61	-0.22	0.82
0.5	-0.48	0.68	-0.15	0.87
0.6	-0.37	0.73	-0.1	0.91

Table 3: Threshold values of the elasticity given for various values of α. At σ_0 the highest share of middle income households' capital $\widetilde{S}/\widetilde{K}$ occurs for $\tau = 0$ and thus wealth inequality is continuously increasing. At σ_1, $(\widetilde{S}/\widetilde{K})(\tau_z) = 1$ and thus wealth inequality is continuously decreasing over the range of all meaningful tax rates. The highlighted row is the standard calibration.



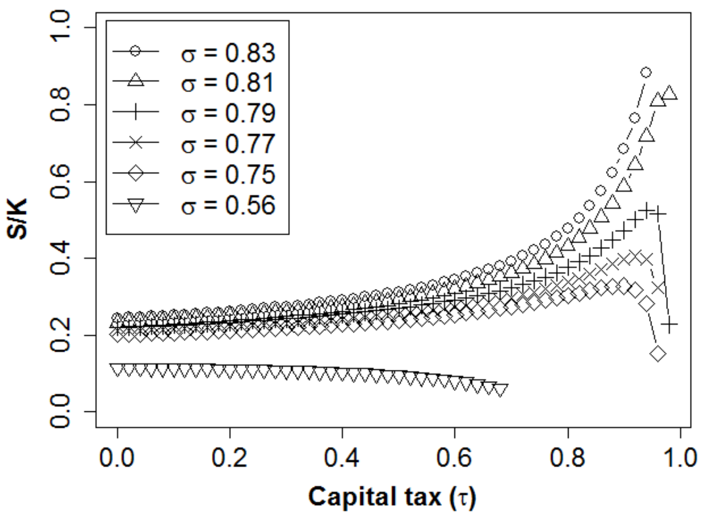


Figure 3: Wealth inequality as a function of the capital tax rate for various elasticties. The upper panel shows selected cases of high elasticities that reproduce the behavior of the Cobb-Douglas function, the lower panel shows cases of low elasticities that illustrate the deviating cases. The middle income households' share of total capital increases monotonically only with high elasticities and decreases monotonically with low elasticites. For middle cases, it increases for low tax rates, but then decreases for high tax rates.

The numerical results on the role of the elasticity of substitution can thus be summarized as follows: Propositions 1 and 2 above are reversed for elasticities of substitution between capital and labor significantly lower than 1, while Proposition 3 still holds. That is, while financing public investment by capital taxation is still Pareto-improving, inequality may be rising and the middle income households may be the class which prefers comparatively lower tax rates. There are critical values of the elasticity of substitution σ at which the effects are reversed: For $\sigma > 0.82$ all of the results obtained for the Cobb-Douglas case $\sigma = 1$ still hold. For $\sigma \leq 0.61$, inequality is rising for all tax rates and middle income households prefer a lower capital tax rate than high income households. In between these values, inequality will first decrease for lower tax

γ	σ	$\tau_{k_c}^{max}$	τ_k^{max}	τ_s^{max}	$\frac{S}{K}\mid\tau_{k_c}^{max}$	$\frac{S}{K}\mid\tau_k^{max}$	$\frac{S}{K}\mid\tau_S^{max}$
0.3	1.43	0.08	0.22	N/A	0.76	0.86	N/A
0	1	0.29	0.36	0.54	0.41	0.43	0.53
-0.2	0.83	0.22	0.24	0.34	0.26	0.27	0.28
-0.3	0.77	0.22	0.24	0.32	0.22	0.23	0.23
-0.5	0.67	0.24	0.24	0.26	0.156	0.156	0.166
-0.8	0.56	0.22	0.22	0.20	0.110	0.110	0.111
-3	0.25	0.08	0.08	0.04	0.009	0.009	0.012

Table 4: The table displays the capital tax values which maximize the different capital stocks and the ratio of middle income household's savings to total capital for these tax rates. It extends Table 1 to varied elasticities between capital and labor. The highlighted row corresponds to the original case of a Cobb-Douglas production function. In the first row, middle income households own all capital for $\tau = 0.35$, which is lower than the value at which $\widetilde{S}$ reaches its maximum.

rates and then increase for higher values. Also in this range, there is a reversal of the class which prefers the higher tax rate. To sum up, in the set-up of the present article, the traditional conclusion that capital taxation is bad for middle and lower classes even if it is spent productively thus holds for low elasticities, despite the Pasinetti property of the model.

4 Conclusion and outlook

This paper shows that under stylized assumptions about heterogeneous saving behavior of households there is no simple equity-efficiency trade-off. We assume that the heterogeneity in saving behavior can be captured in two types of households: High income households save dynastically and their only source of income is capital interest. Middle income households save a portion of their wages for retirement.[8] Under this assumption about households we prove that public investment financed by capital taxation decreases inequality in wealth for any capital tax rate. Middle income households are in favor of a higher capital tax rate than high income households. These results are reversed if the elasticity of substitution between labor and capital is significantly lower than 1. However, low capital tax rates constitute a Pareto improvement over the unregulated outcome for any elasticity. Further, the results establish that for the assumed type of heterogeneity and a high substitution elasticity, balancing the goals of equity and efficiency is not a single trade-off, but is rather characterized by three stages. While the higher the tax, the more equal the wealth distribution, there are three distinct stages regarding efficiency: (i) Low capital taxes (up to 29 % in our model) increase consumption for both classes, there is no trade-off; (ii) higher capital taxes (up to 54 %) still increase *aggregate* output, but decrease consumption of high income households[9]; (iii) all even higher capital taxes decrease both household types' consumption.

[8]Depending on the economy the model represents, low income households can be either assumed to behave similarly or it can be assumed that they do not save and are irrelevant to the present analysis of wealth inequality.

[9]One might expect yet another stage: some range in which there is an increase in the income of the middle income households, but a decrease in aggregate output – which would represent the conventional view on equity and efficiency as conflicting goals. Such a stage does not exist

There are two ways in which the analysis of this article could be extended: First, we only characterized potential policy interventions by their effect on inequality and consumption of the two types of households, eschewing the question which outcome is *socially optimal*. While the question of social optimality in overlapping generation models has been widely discussed (Calvo and Obstfeld, 1988; Heijdra, 2009), we do not know of any treatment of the role of a social planner in models with heterogeneous agents in which some households evolve as overlapping generations and some are infinitely-lived. Several reasonable normative viewpoints are conceivable in such a context. Defending one particular of them will need to answer the following question: With two household types having different time preference rates, does the time preference rate of the social planner only apply to the birth date of subsequent overlapping generations or should the utility of one or both household types also be discounted by this rate?

Second, the model employed in the present analysis relies on a set of very specific assumptions, introduced for isolating the effect of heterogeneous saving behavior and tractability. The results of this article also hold for more general production and utility functions (resulting in non-constant savings rate) and can be extended to other forms of generating fiscal revenue: labor taxation under non-fixed labor supply and consumption taxation. Our companion article confirms numerically that the results of this study hold under these more general assumptions (Klenert et al., 2016).

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in this model because there is no direct transfer to middle income households: When output decreases, both their capital and labor income also decrease.

References

Alesina, A., Rodrik, D., 1994. Distributive politics and economic growth. The Quarterly Journal of Economics 109(2), 465–490.

Aschauer, D. A., 1989. Is public expenditure productive? Journal of Monetary Economics 23(2), 177–200.

Attanasio, O. P., 1994. Personal saving in the United States. In: Poterba, J. M. (Ed.), International Comparisons of Household Saving, pp. 57–124, The University of Chicago Press, Chicago.

Baranzini, M., 1991. A theory of wealth distribution and accumulation. Oxford University Press, Oxford.

Barro, R. J., 1990. Government spending in a simple model of endogenous growth. Journal of Political Economy 98(5), 103–125.

Bom, P. R. D., Ligthart, J. E., 2014. What have we learned from three decades of research on the productivity of public capital? Journal of Economic Surveys 28(5), 889–961.

Browning, M., Lusardi, A., 1996. Household saving: micro theories and micro facts. Journal of Economic literature 34(4), 1797–1855.

Calvo, G. A., Obstfeld, M., 1988. Optimal time-consistent fiscal policy with finite lifetimes. Econometrica 56(2), 411–432.

Carey, D., Rabesona, J., 2002. Tax ratios on labour and capital income and on consumption. OECD Economic Studies 35(2), 129–174.

Chatterjee, S., Turnovsky, S. J., 2012. Infrastructure and inequality. European Economic Review 56(8), 1730–1745.

Chirinko, R. S., 2008. σ: The long and short of it. Journal of Macroeconomics 30(2), 671–686.

Diaz-Gimenez, J., Glover, A., Rios-Rull, J.-V., 2011. Facts on the Distributions of Earnings, Income, and Wealth in the United States: 2007 Update. Federal Reserve Bank of Minneapolis Quarterly Review 34(1), 1–31.

Dutt, A. K., 2015. Growth and distribution in heterodox models with managers and financiers. Metroeconomica, online first. DOI: 10.1111/meca.12102 .

Dynan, K. E., Skinner, J., Zeldes, S. P., 2004. Do the rich save more? Journal of Political Economy 112(2), 397–444.

Futagami, K., Morita, Y., Shibata, A., 1993. Dynamic analysis of an endogenous growth model with public capital. The Scandinavian Journal of Economics 95(4), 607–625.

Gramlich, E. M., 1994. Infrastructure investment: a review essay. Journal of Economic Literature 32(3), 1176–1196.

Green, L., Myerson, J., Lichtman, D., Rosen, S., Fry, A., 1996. Temporal Discounting in Choice Between Delayed Rewards : The Role of Age and Income. Psychology and Aging I, 79–84.

Heijdra, B. J., 2009. Foundations of Modern Macroeconomics. Oxford University Press, Oxford.

Kaldor, N., 1955-1956. Alternative theories of distribution. The Review of Economic Studies 23(2), 83–100.

Klenert, D., Mattauch, L., Edenhofer, O., Lessmann, K., 2016. Infrastructure and inequality: Insights from incorporating key economic facts about household heterogeneity. Macroeconomic Dynamics (in press) .

La Marca, M., 2005. The public sector in a model of growth and distribution à la Pasinetti: Existence of one-or two-class economies. Metroeconomica 56(2), 157–181.

Lawrance, E. C., 1991. Poverty and the rate of time preference: evidence from panel data. Journal of Political Economy 99(1), 54–77.

Michl, T. R., 2007. Capitalists, workers and social security. Metroeconomica 58(2), 244–268.

Michl, T. R., 2009. Capitalists, workers, and fiscal policy: a classical model of growth and distribution. Harvard University Press, Cambridge, MA.

Michl, T. R., Foley, D. K., 2004. Social security in a classical growth model. Cambridge Journal of Economics 28(1), 1–20.

OECD, 2012. Labour losing to capital: What explains the declining labour share? In: OECD Employment Outlook 2012, chapter 3, pp. 109–161, OECD, Paris.

Pasinetti, L. L., 1962. Rate of profit and income distribution in relation to the rate of economic growth. The Review of Economic Studies 29(4), 267–279.

Pasinetti, L. L., 1966. New results in an old framework: Comment on Samuelson and Modigliani. The Review of Economic Studies 33(4), 303–306.

Pasinetti, L. L., 1974. The rate of profit in an expanding economy. In: Growth and Income Distribution: essays in economic theory, pp. 121–146, Cambridge University Press, Cambridge, MA.

Pasinetti, L. L., 2012. A few counter-factual hypotheses on the current economic crisis. Cambridge Journal of Economics 36(6), 1433–1453.

Piketty, T., 2014. Capital in the Twenty-First Century. Harvard University Press.

Piketty, T., Saez, E., 2014. Inequality in the long run. Science 344(6186), 838–843.

Piketty, T., Zucman, G., 2014. Capital is back: Wealth-income ratios in rich countries 1700-2010. Quarterly Journal of Economics 129(3), 1255–1310.

Piketty, T., Zucman, G., 2015. Wealth and inheritance in the long run. In: Atkinson, A. B., Bourguignon, F. (Eds.), Handbook of income distribution. Vol. 2, Elsevier, Amsterdam.

Quadrini, V., 1997. Understanding the U . S . Distribution of Wealth. Federal Reserve Bank of Minneapolis Quarterly Review 21(2), 22–36.

Rognlie, M., 2014. A note on Piketty and diminishing returns to capital. http://gabriel-zucman.eu/files/teaching/Rognlie14.pdf, retrieved 15-10-07.

Romp, W., De Haan, J., 2007. Public capital and economic growth: A critical survey. Perspektiven der Wirtschaftspolitik 8(S1), 6–52.

Russo, A., 2014. A stochastic model of wealth accumulation with class division. Metroeconomica 65(1), 1–35.

Ryoo, S., 2015. Inequality of income and wealth in the long run: A Kaldorian perspective. Metroeconomica, online first: DOI: 10.1111/meca.12096 .

Samuelson, P. A., Modigliani, F., 1966. The Pasinetti paradox in neoclassical and more general models. The Review of Economic Studies 33(4), 269–301.

Steedman, I., 1972. The state and the outcome of the Pasinetti process. The Economic Journal 82(328), 1387–1395.

Stiglitz, J. E., 2015a. New theoretical perspectives on the distribution of income and wealth among individuals: Part II: Equilibrium wealth distributions. National Bureau of Economic Research No. w21190.

Stiglitz, J. E., 2015b. New theoretical perspectives on the distribution of income and wealth among individuals: Part III: Life cycle savings vs. inherited savings. National Bureau of Economic Research No. w21191.

Tavani, D., Zamparelli, L., 2015. Public capital, redistribution and growth in a two-class economy. Metroeconomica, online first. DOI: 10.1111/meca.12105 .

Taylor, L., 2014. The triumph of the rentier? Thomas Piketty vs. Luigi Pasinetti and John Maynard Keynes. International Journal of Political Economy 43(3), 4–17.

Turnovsky, S. J., 1997. Fiscal policy in a growing economy with public capital. Macroeconomic Dynamics 1(03), 615–639.

Wolff, E. N., 1998. Recent trends in the size distribution of household wealth. Journal of Economic Perspectives 12(3), 131–150.

Wolff, E. N., 2010. Recent trends in household wealth in the United States: rising debt and the middle-class squeeze - an update to 2007. The Levy Economics Institute Working Paper Collection 589 .

Wolff, E. N., Zacharias, A., 2013. Class structure and economic inequality. Cambridge Journal of Economics 37(6), 1381–1406.

Zamparelli, L., 2015. Wealth distribution, elasticity of substitution, and Piketty: an anti-dual Pasinetti economy. Working Paper Series. Dipartimento di scienze sociali ed economiche. Sapienza. Università di Roma. No. 1/2015.

Chapter 6

Infrastructure and inequality: insights from incorporating key economic facts about household heterogeneity[1]

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Infrastructure and inequality: Insights from incorporating key economic facts about household heterogeneity

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Abstract

We study the impacts of investment in public capital on equity and efficiency. Taking into account stylized facts on wealth accumulation, we model agent heterogeneity through differences in saving behavior, income source and time preference. We find that in the long run, public investment is Pareto-improving and that it reduces inequality in wealth, welfare and income at the same time, if it is financed by a capital tax. Consumption tax financing is also Pareto-improving but distribution-neutral. Only for labor tax financing, a trade-off between equity and efficiency occurs. Additionally we find that agents differ in their preferred tax rates. The results for capital and labor tax financing are valid for both, the case of decreasing and constant returns to accumulable factors.

JEL classification: E21, E6, H23, H31, H54

Keywords: Public capital, infrastructure, distribution, inequality, heterogeneous saving

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1 Introduction

Public investment in infrastructure has recently received much attention as an attractive option for accomplishing two main objectives of economic policy: Promoting efficiency and growth as well as reducing inequality in wealth. Evidence from the empirical literature suggests that investment in infrastructure can have a decreasing effect on inequality (Calderón and Servén, 2014a), while enhancing growth at the same time (Calderón and Servén, 2014b). The authors assert that for both relationships, little is known about the magnitude of the effects and the underlying mechanisms.

In this article, we confirm that public investment can enhance equality, but show that, in the long run, this depends strongly on the financing mechanism: Capital tax financing can both promote inequality reduction in wealth, welfare and income, and enhance the total level of these variables, when its revenue is spent on public investment. Financing public capital with a consumption tax enhances the efficiency but leaves the level of inequality virtually unchanged. The result on consumption tax financing is, to our knowledge, novel in the literature, as is the result that inequality in wealth and welfare is reduced if public investment is financed by a capital tax. In our analysis, the frequently discussed trade-off between equity and efficiency only occurs for the case of labor tax-financed public investment, which indeed increases inequality in all indicators.

Additionally, the optimal tax level for each household is determined and it is shown that agents differ in their preferred tax rates. This is an extension of the result by Barro (1990) that there is a trade-off between providing productive public investment and its distortionary financing, to the case of heterogeneous households. Nevertheless, up to a certain rate of all taxes, total levels of wealth, welfare and income are always enhanced, making all agents better off, and thus constituting a Pareto improvement. Our results rest on an approach of modeling household heterogeneity that is based on stylized facts about income sources, saving behavior and time preferences.

Previous theoretical work comes to ambiguous conclusions on the distributional effects of infrastructure investment: Alesina and Rodrik (1994) show that inequality-reducing public investment always decreases the efficiency. In Glomm and Ravikumar (1994) it is found that in the long run, the impact of public investment in a productivity-enhancing knowledge stock is neutral on the distribution. The authors consequently argue that there is no equity-efficiency trade-off in the long run when it comes to public investment. Chatterjee and Turnovsky (2012) find that labor and consumption tax financing increase income inequality in the long run, while capital tax financing can decrease income inequality. Regarding the distribution of wealth and welfare, they show that public investment always enhances inequality in the long run, independent of the financing mechanism.

We attribute these results to the way heterogeneity is introduced: In the aforementioned studies, agents differ only in their initial capital endowments. Only Alesina and Rodrik (1994) additionally account for differences in income sources.

A model with these types of heterogeneity assumptions however is not able to reproduce the observed wealth distribution (Cagetti and De Nardi, 2008; De Nardi and Yang, 2014). "[F]or many purposes, the representative-consumer model should be abandoned in favor of a model that matches key microeconomic facts" (Carroll, 2000a; p. 110). Here we comply with this request: By departing from the standard assumptions on heterogeneity our results on consumption tax financing of infrastructure differ from previous studies, as well as the results on capital tax financing, when inequality in wealth and welfare is considered.

In our model we account for the following economic facts:[1] Rich households have been shown to save in a dynastic fashion, while households in the middle income cohorts exhibit more of a life-cycle saving behavior (Attanasio, 1994; Dynan et al., 2004; Browning and Lusardi, 1996). Neither motive in isolation can reproduce the observed wealth distribution (Carroll, 2000b). The wealthier a household is, the more his income sources shift away from wage income towards business and capital income and the more likely it is that he is self-employed (Quadrini, 1997; Diaz-Gimenez et al., 2011; Wolff, 1998). Lawrance (1991) and Green et al. (1996) demonstrate that wealthier households have lower rates of time preference. Krusell and Smith (1998) show that allowing for different time preference rates is a key factor in reproducing the observed wealth distribution.

We develop a general equilibrium model in which high income households are characterized by having a dynastic saving behavior and capital income as their only income source. Middle income households are life-cycle savers, which split their labor income between current consumption and savings for retirement. Low income households do not save or even dissave and are thus omitted.[2] Our model is related to the model developed in Michl (2009) and can also be seen as an extension of the models described in Stiglitz (1969, 2015) that incorporates optimizing agents. High income households are modeled as a representative infinitely-lived agent, and the middle income households are modeled as a representative overlapping-generations agent.[3] The model also allows for agents to differ in their time preference rate. We then calibrate the model to closely match stylized facts of the U.S. economy. In Mattauch et al. (2016) we show analytically, for a basic version of the model, that under these heterogeneity assumptions, capital tax-financed public investment can enhance productivity while reducing inequality. Here we generalize the basic model, in order to assess more channels through which public investment affects the distribution of wealth, welfare and income. We include consumption and labor taxation as revenue-raising mechanisms, introduce a labor-leisure choice and model public capital as affecting both production, and utility.[4] Due to our choice of two optimizing agents with distinct saving behavior, our model does

[1]There are other factors which also influence the wealth distribution but go beyond the scope of this work: For instance the transmission of human capital within families and the existence of public insurance systems (De Nardi and Yang, 2014) as well as differences in rates of return (Guvenen, 2006).

[2]A stylized way to include the low income households in our model is to include them in the middle income group. We explore this approach in Appendix E and demonstrate that it does not change our main results significantly.

[3]In order to highlight the underlying mechanisms we choose to only look at two extreme cases of saving behavior: completely altruistic in the case of the infinitely-lived agent, and pure life-cycle in the case of the overlapping generations agent.

[4]Since most public goods such as for example infrastructure and health care affect productivity and utility at the same time, it is crucial to account for both channels to avoid incorrect conclusions. See Chatterjee and Ghosh (2011) for more details.

not nest the other approaches mentioned before, but instead complements them by accounting for stylized facts on heterogeneous saving behavior.

Our article makes two main contributions. First, we demonstrate that introducing heterogeneity based on empirically observed household behavior has far-reaching consequences: Depending on its financing mechanism (capital, consumption or labor taxation), public investment can either have a decreasing, neutral or increasing impact on inequality. Our second contribution is that our modeling approach yields meaningful results for both endogenous growth and steady-state convergence and our results do not depend on the assumption of homogeneous time preference rates across all agents.

Our concept of heterogeneity, the first contribution, allows us to draw the following conclusions: (i) Higher levels of wealth, welfare and income and a reduced dispersion of these economic variables across households in the long run can be achieved by a policy of capital tax-financed public investment. Regarding income inequality, this result confirms the study by Chatterjee and Turnovsky (2012). It differs from their findings when inequality in wealth or welfare is considered and from the results derived in Alesina and Rodrik (1994) and Glomm and Ravikumar (1994). (ii) Financing public capital through a consumption tax has virtually no effect on the distribution of these variables in the long run.[5] (iii) By determining the tax level that maximizes each household's steady-state utility, we find that households differ in their preferred tax level. As a consequence of this result, there is no single optimal tax rate when financing public investment.

Our second contribution is that our results are very robust with regard to the modeling strategy (see Section 4.2): The results for labor and capital tax financing remain qualitatively the same for endogenous growth as well as for steady-state convergence of the model.[6] All results hold for a wide range of heterogeneous time preference rates across households and the model behavior does not change for homogeneous time preference rates. Furthermore the results remain qualitatively the same if only public capital (as in Barro 1990), or only private capital (as in Romer 1986), is productivity-enhancing.

The remainder of this article is organized as follows: Section 2 outlines the model and its calibration. In Section 3 we characterize the model results for convergence to the steady state. In Section 4.1 we present extensions to the model such as additional financing mechanisms (lump-sum taxes and government debt) for public investment and the endogenous growth version of the model. In Section 4.2 we analyze the model's robustness to variations in the model assumptions and in parameter values. Section 5 concludes the article.

2 Model

The three most important features of the model are that (i) household heterogeneity is modeled through differences in saving behavior and differences in

[5]Other studies do not consider consumption taxes or find a strong negative effect of consumption tax financing on the distribution in the long run.

[6]Most theoretical articles on public investment use endogenous growth models based on Barro (1990) and Turnovsky (1997) since the relationship between growth and public investment is their main focus. Glomm and Ravikumar (1994), by contrast, use a model with steady-state convergence. However, to avoid an indeterminate steady-state wealth distribution, they assume imperfect capital markets. Our model delivers meaningful results for both approaches (without assuming imperfect capital markets).

income sources. High income households whose bequest motive is perfectly altruistic and who rely only on capital income are modeled as a representative infinitely-lived agent. Middle income households who save according to a life-cycle motive are modeled as a representative overlapping-generations agent with labor and capital income. The households can also differ in their time preference rate. (ii) Public and private capital are combined in a weighted product, the composite externality. By varying the weight parameter we can vary the role capital plays in production: When the weight parameter of private capital equals one the role of private capital is analogous to the case examined by Romer (1986). For a weight parameter of private capital equal to zero, public capital plays the same role as in the model by Barro (1990). (iii) Public capital plays a dual role in our model, enhancing both the value of leisure in the utility function, and total productivity. Since it would not provide us with additional insights we neglect population growth and assume that the size of the representative households does not change. Still we account for the fact that the households are different in size in the calibration of the model (see Section 2.7).

2.1 The firm

The production sector is modeled as a single representative firm. Labor is provided by the middle income household only, while both households supply capital. Production occurs with a Cobb-Douglas production function:

$$F(K_t,h_t) = \hat{A}K_t^{\alpha}h_t^{1-\alpha}, \qquad \hat{A} = AX_{p,t}^{\beta}, \qquad 0 < \alpha, \beta < 1 \tag{1}$$

with $h_t = 1 - l_t$ being the portion of the total time endowment that middle income households dedicate to work. The remainder of their time is used for leisure l_t.

$X_{p,t} = K_t^{\varepsilon}K_{G,t}^{1-\varepsilon}$, with $0 < \varepsilon < 1$, represents a composite production externality, modeled as a weighted product of private and public capital. The capital entering the production function is the sum of the middle income households' savings from the last period S_{t-1} and the high income households' capital $K_{h,t}$:

$$K_t = S_{t-1} + K_{h,t}. \tag{2}$$

Note that for $\alpha + \beta < 1$ the economy converges to a steady state. But if $\alpha + \beta = 1$ and if the ratio of public to private capital remains constant, the model will display endogenous growth behavior. This can be deduced by an equivalent of Equation (1):

$$F(K_t,h_t) = AK_t^{\alpha+\beta}(h_t)^{1-\alpha}\left(\frac{K_{G,t}}{K_t}\right)^{(1-\varepsilon)\beta}.$$

A representative firm maximizes its profit:

$$\Pi_t = F(K_t,h_t) - (r_t + \delta_K)K_t - w_t h_t$$

where r_t and w_t represent the rental rates the firms have to pay to the households for capital and labor and δ_k is the depreciation rate of private capital. The following first-order conditions are obtained:

$$r_t + \delta_K = \frac{\partial F(K_t,h_t)}{\partial K_t} = \alpha A\left(\frac{h_t}{K_t}\right)^{1-\alpha} X_{p,t}^{\beta}, \tag{3}$$

$$w_t = \frac{\partial F(K_t, h_t)}{\partial h_t} = (1-\alpha)A\left(\frac{K_t}{h_t}\right)^{\alpha} X_{p,t}^{\beta}. \tag{4}$$

2.2 The high income households

The high income households are modeled as a representative infinitely-lived agent, to which we will also refer as "ILA". They derive utility from either consumption C_t or leisure l_h, which is fixed for the ILA. We later show in Section 4.2.2 that the results of this paper are independent from the level of leisure the high income households receive as long as it remains in a plausible range (see Table 7). Future utility is discounted by the time preference rate ρ_h. Lifetime utility is given by

$$U = \sum_{t=0}^{t_{\text{final}}} u_t^{\text{ILA}} \cdot \frac{1}{(1+\rho_h)^t}, \tag{5}$$

with

$$u_t^{\text{ILA}} = \left(\frac{1}{b}\right)\left(C_t^a + \theta(X_{u,t}l_h)^a\right)^{\left(\frac{b}{a}\right)},$$

where $a = 1 - \frac{1}{\sigma_{\text{Intra}}}$, with σ_{Intra} being the intratemporal elasticity of substitution between consumption and leisure and $b = 1 - \frac{1}{\sigma_{\text{Inter}}}$, with σ_{Inter} being the intertemporal elasticity of substitution. θ is a weight factor for the leisure term and $X_{u,t} = K_t^{\varphi} K_{G,t}^{1-\varphi}$, with $0 < \varphi < 1$, is the composite externality as in the production sector, but with a different exponent φ.

The ILA chooses her levels of consumption C_t and capital accumulation $K_{h,t}$ to maximize Equation (5) according to her budget constraint:

$$K_{h,t+1} - K_{h,t} = (1-\tau_K)r_t K_{h,t} - (1+\tau_c)C_t, \tag{6}$$

where τ_c represents a consumption and τ_k a capital income tax. The agent takes the returns to capital, r_t, as well as all taxes as given by the firm and the government, respectively. Solving the optimization problem yields the following intertemporal decision equation (details on the derivation can be found in the Appendix B):

$$\frac{\left(\frac{\partial u_{t-1}^{\text{ILA}}}{\partial C_{t-1}}\right)}{\left(\frac{\partial u_t^{\text{ILA}}}{\partial C_t}\right)} = \frac{1+(1-\tau_K)r_t}{1+\rho_h}. \tag{7}$$

2.3 The middle income households

The middle income households are modeled as a representative Diamond-type overlapping-generations agent, to whom we will also refer as an "OLG" agent and who lives for just two periods. The duration of each period is thirty years. In the first period the agent decides how to divide her fixed time endowment (which is normalized to 1) between work ($h_t = 1 - l_{y,t}$) and leisure ($l_{y,t}$) and how much of her labor income (w_t) she saves for the second period (Equation 9). In the second period, the savings plus the interests are consumed (see Equation 10). We use the subscript "y" to denote the young (first-period) agent, and "o" to denote the old (second-period) agent.

The lifetime utility of the OLG agent is given by:

$$u_t^{\text{OLG}} = \frac{1}{b}\left(C_{y,t}^a + \theta(X_{u,t} l_{y,t})^a\right)^{\frac{b}{a}} + \frac{1}{(1+\rho_m)}\frac{1}{b}\left(C_{o,t+1}^a + \theta(X_{u,t+1} l_o)^a\right)^{\frac{b}{a}}, \quad (8)$$

where l_o is the fixed leisure endowment of the old agent. We show in Section 4.2.2 that the level of this parameter does not change the character of the results as long as it remains in a plausible range. The young agent discounts her own old age by a factor ρ_m. The agent chooses $l_{y,t}$ and S_t to maximize her lifetime utility subject to the two budget constraints:

$$(1+\tau_c)C_{y,t} = (1-\tau_w)w_t(1-l_t) - S_t \quad (9)$$

$$(1+\tau_c)C_{o,t+1} = (1+(1-\tau_K)r_{t+1})S_t, \quad (10)$$

where τ_w is a tax on labor. Solving the optimization problem yields the equations of the inter- and intratemporal decision problem (details on the derivation can be found in the Appendix C):

$$\frac{\left(\frac{\partial u_t^{\text{OLG}}}{\partial C_{y,t}}\right)}{\left(\frac{\partial u_t^{\text{OLG}}}{\partial C_{o,t+1}}\right)} = (1+(1-\tau_K)r_{t+1}), \quad (11)$$

$$\frac{\left(\frac{\partial u_t^{\text{OLG}}}{\partial C_{y,t}}\right)}{\left(\frac{\partial u_t^{\text{OLG}}}{\partial l_{y,t}}\right)} = \frac{(1+\tau_c)}{(1-\tau_w)\cdot w_t}. \quad (12)$$

2.4 The government

The government levies taxes to finance investment in a public capital stock K_G. Public capital depreciates at the rate δ_G. The tax level is set exogenously, which means that the government does not optimize. We nevertheless can find the preferred tax rates of each agent by comparing their utilities in different steady states. The government's budget equation is thus

$$K_{G,t+1} - K_{G,t} = \tau_K \cdot r_t \cdot K_t + \tau_w \cdot h_t \cdot w_t + \tau_c \cdot (C_t + C_{y,t} + C_{o,t}) - \delta_G K_{G,t}. \quad (13)$$

Subsequently, the relative merit of financing public investment by the three distinct taxes will be compared.

2.5 Equilibrium and the Pasinetti Paradox

For $\alpha+\beta<1$ the system converges to a steady state for all parameter combinations evaluated numerically (see Table 1 for the standard calibration and Table 7 for the parameter ranges evaluated in the sensitivity analysis). In the following, variables at their steady-state levels are denoted by a tilde. We see from Equation (7) that in the steady state, the high income households' rate of pure time preference determines the interest rate of the aggregate economy $\tilde{r}$:

$$\frac{1+(1-\tau_K)\tilde{r}}{1+\rho_h} = 1 \Rightarrow \tilde{r} = \frac{\rho_h}{(1-\tau_K)}. \quad (14)$$

This entails that in our model a form of the Pasinetti (1962) Paradox occurs. In its original formulation the paradox states that in a Solow model with two types of households, one of them only receiving income through capital interests – the "capitalists" – the steady-state interest rate is solely determined by the "capitalists" savings rate. Similarly, in our framework the long-run interest rate is only determined by the high income households' time preference rate (and the capital tax rate), independent of the high income households' income sources. The paradox furthermore implies that when middle income households increase their saving, the high income households' saving will be relatively lower. For more details on the Pasinetti Paradox in the context of a simpler version of this model see Mattauch et al. (2016). Note that the Pasinetti Paradox does not occur for endogenous growth, since in that case the interest rate no longer depends only on the time preference rate of the high income household. The remaining equations that characterize the steady state can be found in Appendix D.

2.6 Measure of distribution

We take the coefficient of variation σ_j with $j \in [\mathrm{K}, \mathrm{U}, \mathrm{Inc}]$ as a measure of dispersion in wealth, welfare and income (see e.g. Ray 1997 for details on inequality measures). The cohorts represented by the two agents are of unequal size (see Chapter 2.7 on calibration), which has to be reflected in the calculation of the coefficient. In the following N is the total size of both cohorts, while N_m and N_h stand for the size of the middle and the high income cohort. The index "*pc*" marks a per capita variable:

$$\sigma_K = \frac{\sqrt{\frac{1}{N}\left(N_\mathrm{m}(S_\mathrm{pc} - \mu_K)^2 + N_\mathrm{h}(K_{h,\mathrm{pc}} - \mu_K)^2\right)}}{\mu_K},$$

with μ_K being the mean:

$$\mu_K = \frac{N_\mathrm{h} K_{h,\mathrm{pc}} + N_\mathrm{m} S_\mathrm{pc}}{N}.$$

2.7 Calibration

We calibrate the model such that in the baseline scenario the high income households make up five percent of the population, while owning 62 % of total wealth and the middle income households make up the next 55 % of the population while owning the remaining 38 % of total wealth. These numbers are chosen to match a study on the wealth distribution in the U.S. (Wolff, 2010). The model also roughly complies with the fact that 50–60 % of U.S. net worth accumulation is due to wealth transfers from one generation to another (Gale and Scholz, 1994). In the baseline scenario a minimal stock of public capital is already provided through a consumption tax, which is the least distortionary of the three types of taxes.

The above results use the parameterization displayed in Table 1. All values are chosen for timesteps of thirty years.

We use the study by Chatterjee and Turnovsky (2012) as a benchmark for our calibration. Whenever we deviate from their calibration the reason lies in the different type of household heterogeneity used in our model: We model the households such that high income households have a lower time preference rate than middle income households, in accordance with Lawrance (1991), Dynan et al. (2004) and Green et al. (1996). Leisure is constant for

Symbol	Parameter	Value	Value (p.a.)
α	Elasticity of capital in production	0.4	–
β	Exponent of public capital in production	0.2	–
δ_G	Depreciation of public capital	0.7	4%
δ_k	Depreciation of private capital	0.7	4%
ε	Private capital share in $X_{p,t}$	0.6	–
φ	Private capital share in $X_{u,t}$	0.6	–
l_h, l_o	Leisure of agents with only capital income	0.71	–
ρ_h	High inc. households' time preference rate	0.45	1.2%
ρ_m	Middle inc. households' time preference rate	6	6.7%
σ_{Inter}	Intertemporal elasticity of substitution	0.4	–
σ_{Intra}	Intratemporal elasticity of substitution	0.76	–
θ	Share of leisure in utility function	1.75	–

Table 1: Standard calibration of the model

agents receiving only capital income, which is true for the old middle income household and the high income household. These assumptions are analyzed for their robustness in Section 4.2.2. The parameter ranges in which our results remain qualitatively the same is given in Table 7.

3 Results

In this section we present the results for the case of decreasing returns to accumulable factors and thus of convergence to the steady state.We assess the impact of our assumption of household heterogeneity on the performance of three revenue-raising mechanisms for public investment: capital income taxation, labor income taxation and consumption taxation. We analyze the impact of these policies on wealth, welfare, income, the distribution of these variables between different households, and on aggregate output. The various policies are evaluated relative to a scenario in which a basic level of public capital is supplied by a 2 % consumption tax.

In the long run, investment in public capital can be inequality-decreasing, distribution-neutral or inequality-increasing, depending on the financing mechanism: Capital taxation as a financing option reduces inequality, while a labor tax increases inequality and consumption taxation has a neutral effect on the distribution.[7] All three financing mechanisms promote efficiency up to a certain tax level.

Furthermore, by comparing the steady-state utility levels for varied tax values, we determine the tax level that maximizes each household's welfare for each financing mechanism.

The short-run distributional effects can, for some financing mechanisms, be contrary to the long-run effects: for instance, a labor tax can decrease short-run wealth inequality even though it is inequality-increasing in the long run. A consumption tax is almost distribution-neutral in the long run, but has strong distributional impacts in the short run.

This section is structured as follows: In the first part, Section 3.1, we describe the effect of each financing mechanism for public capital for the case of

[7]In Section 4.1 we also consider financing of public capital through government bonds and lump-sum taxes.

convergence to the steady state. We discuss the effects of the policy on welfare, capital and income of each agent, as well as on aggregate output and on the dispersion of wealth, welfare and income. Furthermore, each household's welfare-maximizing tax level is determined for each financing mechanism. In Section 3.1.4 the different financing mechanisms are compared in terms of their efficiency and equity implications. Finally, in Section 3.2, we describe the effects of the policies on the transitional dynamics.

3.1 Long-run results

In this section we investigate the long-run effects of increased public investment for a broad range of exogenously given capital, labor and consumption tax rates. We write dX to denote the percentage change of the variable X with respect to the baseline scenario of a 2 % consumption tax.

To avoid a discussion on how to compare aggregate utilities of short-lived OLG agents to that of infinitely-lived agents, in this section we only consider steady-state utility levels, to which we will refer as welfare. We denote the tax levels that maximize output and each agent's welfare level as $\tau_Y^{\max}$, $\tau_{u,\mathrm{ILA}}^{\max}$ and $\tau_{u,\mathrm{OLG}}^{\max}$.

3.1.1 Capital tax

When financing an increase in public capital with a tax on capital income, we find the following four effects:

1. Dispersion in wealth, welfare and income decreases for rising τ_k (see Figure 1 on the left).
2. Output is maximized for a 30 % capital tax.
3. For tax rates up to 64 % the policy is Pareto-improving (see Figure 1 on the right).
4. Middle income households prefer a higher capital tax rate (40%) than high income households (30%) (see Figure 1 on the right).

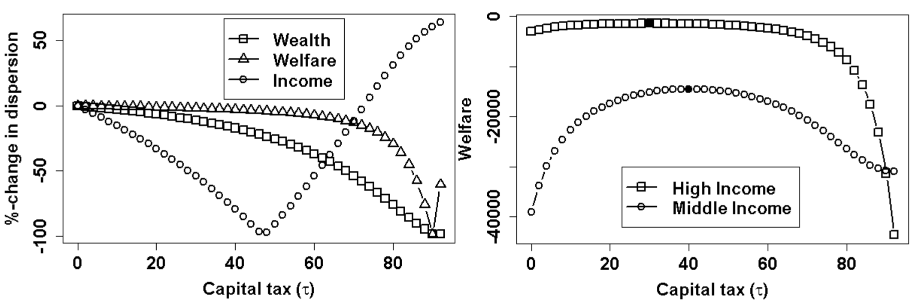

Figure 1: Effects of capital tax-financed public investment on the dispersion of wealth, welfare and income (left side) and on the welfare of both agents (right side). The downward spikes in the left figure reflect the points where middle income households are equal in a certain variable to high income households. For even higher tax rates the dispersion increases again, but this time the middle income households are comparatively better off.

	dY(%)	du_{ILA}(%)	du_{OLG} (%)	$d\sigma_K$ (%)	$d\sigma_u$ (%)	$d\sigma_{\text{Inc}}$ (%)
$\tau_Y^{\max} = 0.3$	31.5	53.6	61.5	-10.8	-1.8	-54.2
$\tau_{u,\text{ILA}}^{\max} = 0.3$	31.5	53.6	61.5	-10.8	-1.8	-54.2
$\tau_{u,\text{OLG}}^{\max} = 0.4$	29.1	51.3	63.2	-16.9	-2.9	-79.1

Table 2: Steady-state effects of a capital tax-financed increase in public spending. In the column on the left, the levels of capital tax rates which maximize output and utility of the different agents are given. In the remaining columns the changes in output, welfare and dispersion are given in percent, as compared to the baseline.

These results are explained as follows: Since the model has the Pasinetti property (see also Section 2.5), a capital tax increases the interest rate in the long run (see Equation 14), high income households reduce their savings and thus the income and wealth dispersion decreases. For low capital taxes the public capital stock and with it the composite externality increases, which increases the returns to labor (see Equation 4) and thus further decreases the dispersion in income.[8] These effects combined lead to a larger reduction in consumption and thus in welfare for high income households than for middle income households. Thus dispersion in all three variables decreases.[9]

A Pareto improvement exists because of the positive effect of the composite externality on utility and production. Whenever the positive effect of public investment outweighs the negative effect of taxation Pareto improvements are possible.

3.1.2 Labor tax

A labor tax affects only the middle income households, since the high income households do not receive any labor income. The effects of labor tax-financed public capital are displayed in Figure 2. Our main findings are:

1. Dispersion in all three variables increases (see Figure 2 on the left).
2. Output is maximized for a labor tax bigger than 92 %.
3. The policy is Pareto-improving up to more than 92% (see Figure 2 on the right).
4. Middle income households prefer a lower income tax rate (68%) than high income households ($>$ 92 %) (see Figure 2 on the right).

The intuition behind these results is as follows: A labor tax solely affects the middle income households' income, which increases the income dispersion strongly. Since the middle income households' saving decision depends on the level of the wage income, their savings decrease, which causes the wealth dispersion to increase. Labor taxation increases the leisure consumption ratio,

[8]Some parts of the tax incidence also fall on the middle income households through the depressing effect a capital tax can have on the wage rate. In our model this effect is offset by the positive effect of public investment on both factors.

[9]In the case of a capital tax the labor-leisure decision plays only a minor role: Total leisure for the middle income households is slightly decreased since the value of leisure increases due to an increase in the composite externality. The composite externality increases as long as the increase in public capital offsets the decrease in private capital.

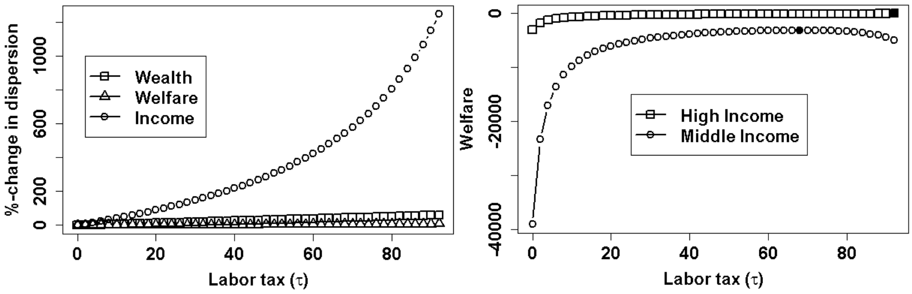

Figure 2: Effects of labor tax-financed public capital on the dispersion of wealth, welfare and income (left graph) and on the welfare of both agents (right graph). The high income households prefer the maximum wage tax rate, since they do not receive wage income but benefit from public investment. The tax rate preferred by the middle income households is quite high, which is a consequence of the current calibration, where the benefits of public investment outweigh the negative effects of a labor tax up to a tax rate of 68%.

	dY(%)	du_{ILA}(%)	du_{OLG} (%)	$d\sigma_K$ (%)	$d\sigma_u$ (%)	$d\sigma_{Inc}$ (%)
$\tau_Y^{\max} > 0.92$	443.2	98.4	87.8	59.4	7.9	1245
$\tau_{u,\text{ILA}}^{\max} > 0.92$	443.2	98.4	87.8	59.4	7.9	1245
$\tau_{u,\text{OLG}}^{\max} = 0.68$	276.9	96.7	92.2	43.9	5.3	539.6

Table 3: Steady-state effects of a labor tax-financed increase in public spending. In the column on the left, the levels of labor tax rates which maximize output and utility of the different agents are given. In the remaining columns the changes in output, welfare and dispersion are given in percent, as compared to the baseline. Some values are outside the feasible range of taxes in our model and are thus marked with a “>” sign.

which can be seen in Equation (C.5). The increasing composite externality has an opposing effect on the leisure consumption ratio (since $a < 0$, for $\sigma_{Intra} < 1$), which dominates with the current parameterization (specified in Section 2.7), so leisure decreases. The high income household experiences a stronger increase in welfare due to its non-taxed income and the leisure-enhancing effect of the composite externality, while the middle income household has reduced consumption through labor income taxation and reduced leisure, which causes inequality in welfare also to increase. The mechanism for the Pareto improvement described for the capital tax also applies here, it is even stronger since labor taxation decreases the private capital stock less than capital taxation.

3.1.3 Consumption tax

The consumption tax has the broadest tax base of the three taxes since the burden falls on all households: the infinitely-lived agent, as well as the young and the old overlapping-generations agents are taxed. Financing public capital with a consumption tax has the following effects:

1. Output is maximized for a tax rate of > 90 %.

2. The policy is Pareto-improving for consumption taxes up to more than 90 % (see Figure 3 on the right).

3. Both households prefer a consumption tax > 90 % (see Figure 3 on the right).

4. Dispersion in all three variables changes only slightly (see Figure 3 on the left).

	dY(%)	du_{ILA}(%)	du_{OLG} (%)	$d\sigma_K$ (%)	$d\sigma_u$ (%)	$d\sigma_{Inc}$ (%)
$\tau_Y^{\max} > 0.9$	221.3	91.4	92.6	-0.3	-1.4	-0.7
$\tau_{u,\mathrm{ILA}}^{\max} > 0.9$	221.3	91.4	92.6	-0.3	-1.4	-0.7
$\tau_{u,\mathrm{OLG}}^{\max} > 0.9$	221.3	91.4	92.6	-0.3	-1.4	-0.7

Table 4: Steady-state effects of a consumption tax-financed increase in public spending. In the column on the left, the levels of consumption tax rates which maximize output and utility of the different agents are given. In the remaining columns the changes in output, welfare and dispersion are given in percent, as compared to the baseline. Some values are outside the feasible range of taxes in our model and are thus marked with a ">" sign.

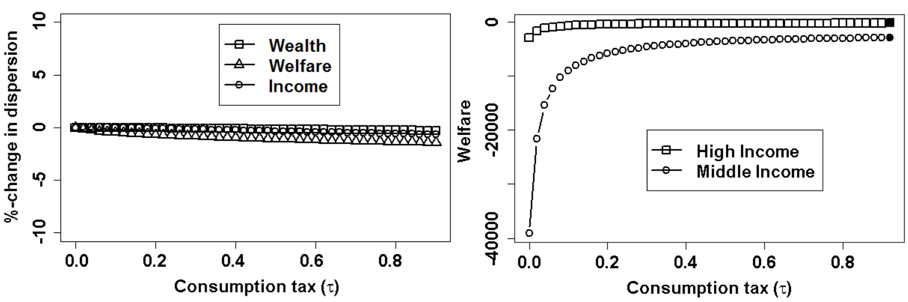

Figure 3: Effects of consumption tax-financed public capital on the dispersion of wealth, welfare and income (left side) and on the welfare of both agents (right side).

Consumption tax-financed public capital acts on the distribution in three ways: (i) The burden of the consumption tax itself falls on all agents (young/old OLG agent and ILA). However, the young OLG agent can react to the tax by adjusting its labor supply. For the other agents, leisure is assumed to be constant. A reduction in leisure reduces the leisure component in the utility function but potentially increases income due to more hours worked. (ii) Public capital entering the production affects all agents via increased factor prices (in the short run). In order to maintain the interest rate at its Pasinetti level, the high income household has to decrease its savings rate relative to that of the middle income household. The long-run wage rate remains at increased levels in the steady state, which leads to an increased steady-state income and increased saving for the middle income household. (iii) Public capital entering the utility function increases both agents' utility obtained through leisure. Only the young OLG agent has an endogenous labor-leisure choice and can react to increased public spending. For the standard calibration, an increase in public capital leads to a decrease in leisure (see also equation C.5), which leads to an increased income.

In sum these effects lead to the following outcome: The leisure-reducing effect of public capital (iii) outweighs the direct effect of the consumption tax

(i) by far, so the leisure of the young OLG agent decreases. For the standard calibration and the parameter variations given in Table 7, the increase in the high and the middle income households' income is almost of the same size, so the resulting difference in the income, wealth and welfare distribution are very small and this policy appears almost distribution-neutral.[10]

Consumption tax financing always increases efficiency up to very high tax rates, since the Pasinetti property of the model ensures high capital accumulation, which has a positive effect on wages. Both agents steady-state income is then increased. Even though the agents' consumption decreases at some point, the utility-enhancing effect of public capital more than compensates for this loss. For that reason all agents prefer consumption tax levels up to 90 %.

3.1.4 Summary: Comparing the different taxes

In our model tax-financed public capital acts on the distribution in three different ways: First, through a change in the policy, the aggregate level of capital changes. Second, agents are affected differently by different tax instruments and finally, agents react to policies by changing their leisure level and their saving behavior. Since all taxes differ in their impact on aggregate capital, in their differential impact on the households and on the labor-leisure choice, each tax has different effects on equity and efficiency.

When comparing the results from Tables 2, 3 and 4, two main differences become apparent:

(i) The dispersion in all variables is strongly reduced by capital tax financing of public spending, while labor tax financing increases it. A consumption tax hardly changes the dispersion in all variables.

(ii) A consumption tax enhances the economy's output the most for a tax rate up to 20 %. Above that threshold a labor tax outperforms the consumption tax, while a capital tax performs worst. We attribute this to the disincentive to accumulate capital caused by the capital tax. For higher tax levels aggregate efficiency is highest for labor taxation, since labor taxation in this setup reduces leisure time thus causing middle income households to work more and thereby increasing the public capital stock.

(i) and (ii) together suggest an equity-efficiency trade-off between inequality-reducing capital tax financing and efficiency-enhancing consumption tax financing.

By contrast all taxes constitute a Pareto improvement up to a certain tax rate. This result depends crucially on the base level of public capital. When the public capital stock is already at its optimal level, further investment does not enhance both agents' welfare and thus will not lead to a Pareto improvement.

The fact that the optimal tax rates (and with it the optimal levels of infrastructure provision) differ between the households has an important consequence for an optimizing government: Providing infrastructure beyond the

[10] Consumption tax financing can be slightly regressive or progressive, conditional on the role leisure plays in the utility function: Depending on the leisure endowment of old middle income households l_o and the intratemporal elasticity of substitution σ_{Intra}, the change in dispersion varies between $[-4.7\%, 2.3\%]$ for the parameter ranges of these variables examined in the sensitivity analysis (see Table 7). Nevertheless these distributional effects are still more than an order of magnitude smaller when compared to the other financing mechanisms. See Section 4.2.2 for details on the sensitivity analysis.

optimum of one of the two classes, always involves a trade-off between the welfare of the different classes, at least for capital and labor tax financing. For those financing instruments, further normative assumptions would be necessary to determine the optimal tax level. Those normative assumptions can be avoided if infrastructure is financed via consumption taxes: For this case the trade-off between the middle and the high income household disappears since both agents prefer the same tax rate.

3.2 Transitional dynamics

In addition to the steady state analysis we also analyze the transitory dynamics of the system, since short-run distributional effects can go into opposite directions than long-run effects. We examine the impact of an unanticipated policy shock: When the system is in a steady state, public spending is increased from the baseline level to a level which increases output by 30 %.

We find two main results: (i) Short-term effects opposite to the long-run outcome are found only in the case of labor taxation: Wealth inequality is decreased in the short run, but then converges to a steady state with increased wealth inequality (see Figure 9 in Appendix A). (ii) A consumption tax has almost no long-run effects on the distribution, but strong short-run effects. Wealth inequality is decreased while income inequality is strongly increased in the short run (see Figure 4). The dynamics for a capital tax are displayed in Figure 10, which can be found in Appendix A.

Short-term effects for both labor and consumption can be explained as follows. The slight initial decrease in the wealth distribution can be attributed to the Pasinetti property of the system: A sudden increase in public spending increases both factor prices, thus saving of both agents increases. Since the high income household wants to force the interest rate back to the Pasinetti level, she decreases her saving. Wealth inequality is then reduced until the interest rate converges to the Pasinetti level, determined by high income household's time preference rate. The strong reaction of the income distribution for a labor and a consumption tax can also be explained by the Pasinetti Paradox: A sudden increase in public spending increases both factor prices. Since the interest rate before the shock is already at its Pasinetti level, the productivity-enhancing shock causes the interest rate to converge to its steady-state levels from above, while the wage rate converges to its steady-state levels from below. This leads to higher capital income than wage income in the short run and thus to increased income inequality. This effect is not visible at the moment of the shock, $t = 0$, since the savings level of the middle income household has already been determined in the time step preceding the shock.

In the case of capital taxation (see Figure 10, Appendix A) dispersion in all variables converges to its steady-state value without noteworthy short-run effects except for the strong initial decrease in the income dispersion which accrues to the fact that middle income households determine their savings in the period before the shock.

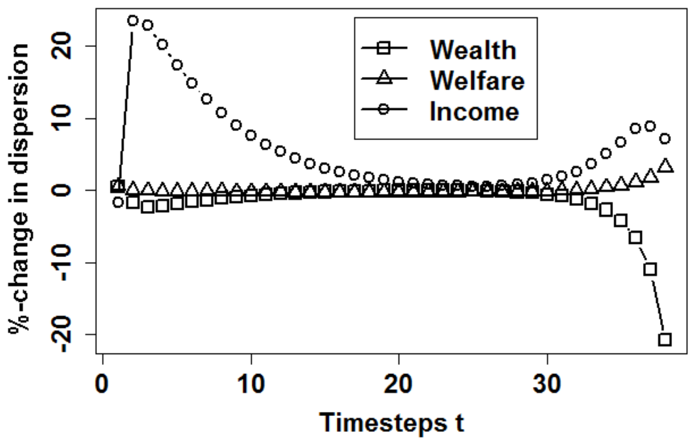

Figure 4: Transitory effects of an unanticipated increase of the consumption tax from the baseline steady state to a new steady state. The new steady state has a 30 % higher output level than the baseline. Even though the long-run effects of consumption tax-financed public investment are almost distribution-neutral, there are strong short-run effects.

4 Extensions and robustness

This section consists of two main parts. In Subsection 4.1, we present three extensions to the model: the case of endogenous growth, lump-sum tax-financed public spending and debt-financed public spending.

An extensive discussion of the robustness of our findings is presented in Subsection 4.2. We focus on both, the robustness across theories and assumptions (Subsection 4.2.1), as well as on the robustness across parameter values (Subsection 4.2.2).

4.1 Extensions

4.1.1 Endogenous growth analysis

This section summarizes our findings from the endogenous growth version of the model. It can be seen as the analogue to Section 3.1 for the case of endogenous growth. In order to obtain constant instead of diminishing returns in accumulable factors, we set $\beta = 1 - \alpha$ (see Section 2.1). For this parameter choice the economy converges to a steady growth path on which consumption and capital for both agents, as well as output, public capital and the composite externality grow at the same rate g.

The differences to the steady state analysis are mainly driven by the fact that the Pasinetti Paradox does not occur in the case of endogenous growth (for more details on the Pasinetti Paradox see Section 2.5). Along the growth path we consider changes in the growth rate rather than in output as an indicator of efficiency.

We obtain three main results: (i) Similar to the steady state analysis, consumption tax-financed public investment is the most efficient policy, at least up to 20%, followed by a labor tax financing. Capital tax financing is the least growth-enhancing policy (see Figure 5). (ii) Capital and labor taxation yield results very similar to the steady state analysis, except for slight variations in the case of low tax rates, which are explained below (Figure 6 a, b). (iii) The results for a consumption tax deviate from the steady-state results (Figure 6 c). This behavior is analyzed in detail below.

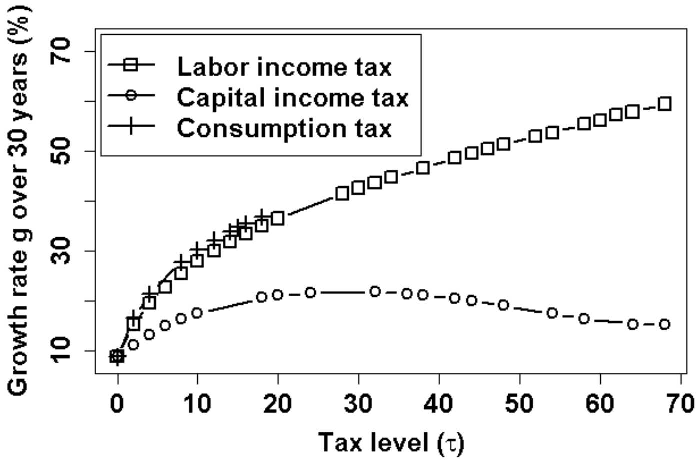

Figure 5: Effects of public investment on the steady-state growth rate: A consumption tax is the most growth-enhancing way to finance infrastructure investment, directly followed by a labor tax. A capital-tax is the least growth-enhancing policy instrument. Growth reaches its maximum already at a 30 % capital tax, while the other taxes enhance growth up to their maximum levels.

For labor tax rates up to 20 %, income and welfare dispersion increase as in the steady state analysis (see Figure 6 b). But wealth dispersion slightly decreases, an effect which we only obtain because public capital is very productive in the case of endogenous growth. This outcome can be explained by examining the effects of an increase in labor tax-financed infrastructure spending:

(1) Leisure (l_t) decreases because the quality of public capital is enhanced, while total capital increases. This leads to a decreased interest rate and an increased wage rate (see Equations 3 and 4).

(2) Public capital and thus the composite externality is increased, which enhances both the interest and the wage rate.[11]

(3) Combining both (1) and (2) leads to increases in both factor prices since effect (2) outweighs effect (1) for the interest rate. However it also leads to an increased ratio of wage rate to interest rate due to effect (1).

For small tax rates the productivity-enhancing effect of public capital more than offsets the negative effect of taxation and due to (3), the middle income

[11] An effect unobserved in the case without endogenous growth, in which the interest rate always stays at the level determined by the high income households' time preference rate due to Pasinetti's Paradox.

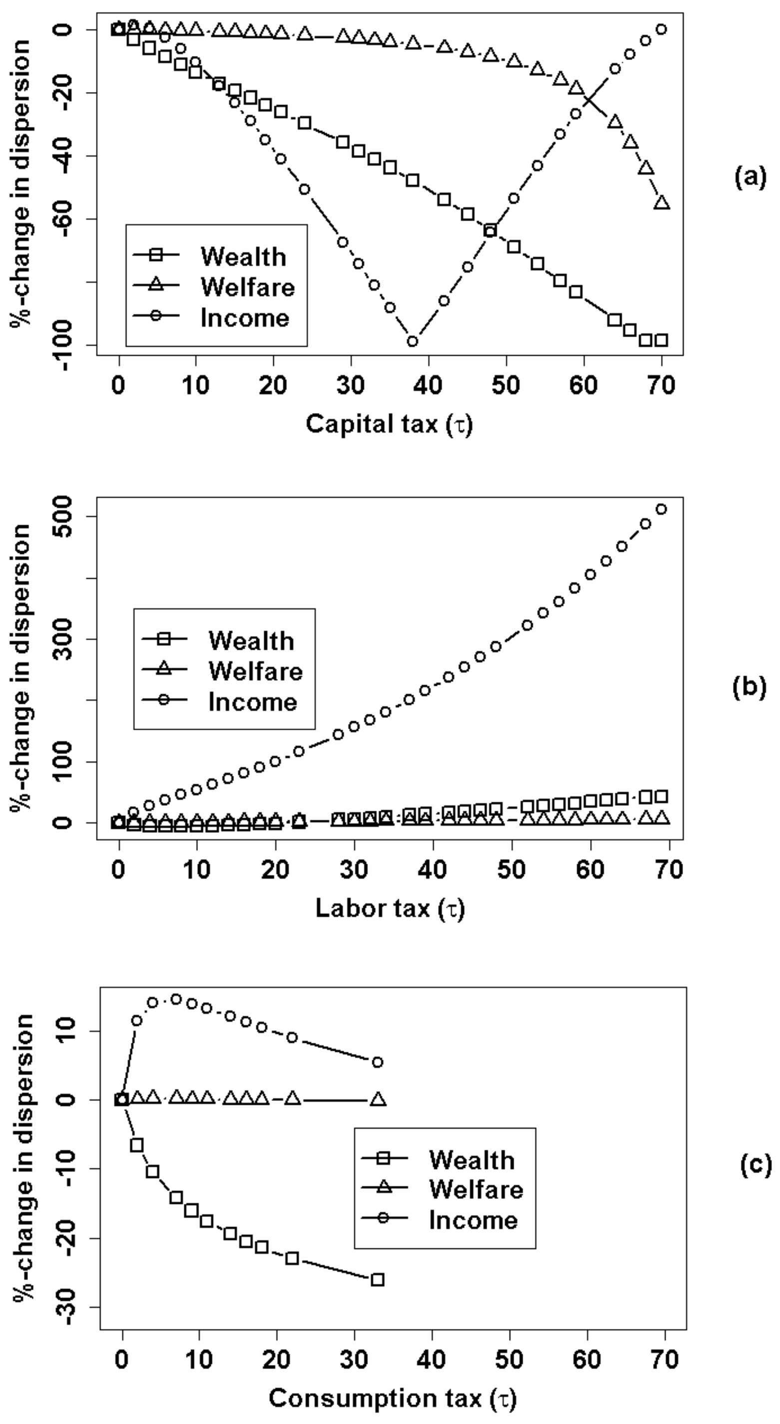

Figure 6: Effects of infrastructure financing through (a) capital, (b) labor and (c) consumption taxation on the dispersion of wealth, welfare and income for the case of endogenous growth. The downward spikes in Panel (a) reflect the points where middle income households are equal in a certain variable to high income households. For even higher tax rates the dispersion increases again, but this time the middle income households are better off.

households' savings are affected more strongly by labor tax-financed public spending than the high income households' savings.[12]

For tax rates below 8 %, effect (2) is also at work in the case of a capital tax, which leads to a small increase in income dispersion (see Figure 6 a). From 8 % on the negative effect of capital taxation outweighs this effect. Both of these effects are quite small for our current parameterization.

Consumption tax-financed infrastructure investment leads to a decreased wealth dispersion, but to an increase in income dispersion for taxes up to 10 %. For higher consumption taxes the income dispersion declines as well. There is hardly any effect on welfare dispersion (Figure 6 c).

The mechanisms of an increase in the consumption tax are the same as for a labor tax, so (1) to (3) still hold. But the negative effect of labor taxation on the middle income households' income is missing, so for tax rates above 10 %, the middle income households' income is affected more strongly by infrastructure spending than the high income households' income and thus income dispersion declines from this point on. For tax values below 10 % the strong productivity-enhancing effect of infrastructure investment causes the capital component of the income to increase more strongly than the labor component, which leads to an increase in the income dispersion.

4.1.2 Lump-sum tax financing

A lump-sum tax provides a meaningful benchmark, but it is not a feasible policy instrument in real-world politics. We introduce the case of lump-sum tax-financed public spending to exclude the distortive effects the other taxes have on the economy. This allows to decouple to the distributional effect of public spending from that of its financing.[13]

When the model converges to a steady state we find that lump-sum taxes distort the economy far less than the other tax mechanisms and therefore lead to the highest output levels (770 %, see Table 5).

	dY(%)	du_{ILA}(%)	du_{OLG} (%)	$d\sigma_K$ (%)	$d\sigma_u$ (%)	$d\sigma_{Inc}$ (%)
$\tau_Y^{max} = 0.82$	770	92.8	93.1	−50.7	−0.3	−90.1
$\tau_{u,ILA}^{max} = 0.58$	528.7	95.6	95.0	−36.9	1.2	−81.0
$\tau_{u,OLG}^{max} = 0.56$	509.9	95.6	95.0	−35.8	1.1	−78.6

Table 5: Steady-state effects of a lump-sum tax-financed increase in public spending. In the column on the left, the levels of lump-sum tax rates which maximize output and utility of the different agents are given. The remaining columns display the changes in output, welfare and dispersion in percent, as compared to the baseline. The lump-sum tax is given in percentage of output.

[12]This effect is not visible in the income dispersion since the labor component of the middle income households' income benefits less from labor tax-financed infrastructure spending than the capital component due to the negative impact of the labor tax. The overall effect is that the middle income households' income benefits less from infrastructure spending than the high income households' income.

[13]We implement the lump-sum tax such that each household pays the same amount in per capita terms. Since high income households only make up 5 % of the population, middle income households make up 55 % and low income households are not included, high income households end up paying 1/12 of the lump-sum tax, while middle income households pay for the remaining 11/12.

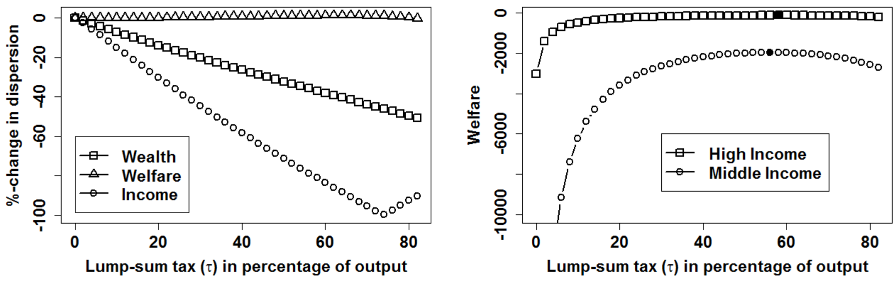

Figure 7: Effects of lump-sum tax-financed public investment on the dispersion of wealth, welfare and income (left side) and on the welfare of both agents (right side).

Concerning the distributional effects in the steady state (see Figure 7, left), welfare inequality is slightly increased while wealth and income inequality decrease. Those distributional effects are a consequence of the Pasinetti property of the model: The interest rate remains at the level of the high income household's time preference rate, even though increased public spending and increased working hours have an increasing effect on both factor prices. The only control variable for the high income household to maintain the interest rate at its Pasinetti level is its saving, which is thus reduced compared to the middle income household's saving, which leads to decreased wealth and income inequality. Welfare inequality remains almost unchanged, since the middle income household's welfare increase that occurs through increased income, is offset by its leisure reduction. As in the case of capital and labor tax financing, there is a difference between the tax rates that maximize output and those that maximize welfare of the different households (see Table 5 and Figure 7, right).

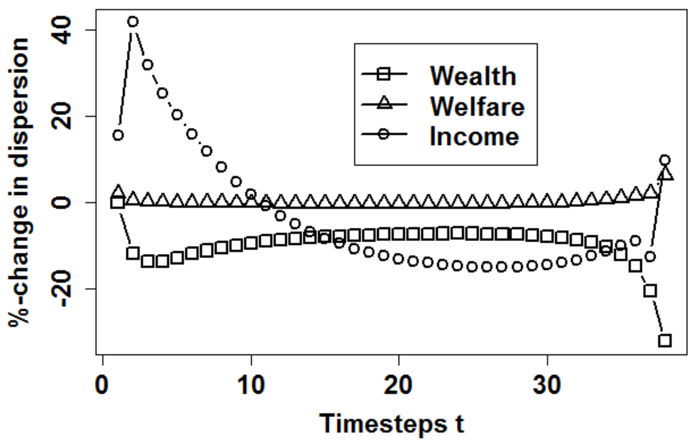

Figure 8: Transitory effects of an unanticipated increase of the lump-sum tax from the baseline steady state to a new steady state (in which the lump-sum tax amounts to 10 % of the economy's output).

The distributional effects in the transition to the steady state are displayed in Figure 8. While welfare inequality converges smoothly to its steady-state levels, inequality in income and wealth converge less smoothly: Through the initial productivity-enhancing effect of public capital both factor prices increase, which causes the high income household's income to rise faster than that of the middle income household, so income inequality is increased in the first timesteps after the shock. In the following timesteps the interest rate converges to its steady-state rate from above, while the wage rate converges to its steady-state level from below. This causes income inequality to decrease, eventually below its initial level. Wealth inequality decreases strongly in the beginning, since the high income household's only reaction to high interest rates is to decrease its saving relative to the saving of the middle income household. With the interest rate returning to its Pasinetti level, the wealth distribution converges to its steady-state level from below. Figure 8 considers an increase in the lump-sum tax from 0 to 10% of output. [14]

4.1.3 Public debt

Since government debt is frequently observed as a means for financing public investment in the real world, we summarize the results of an analyis on the distributional effects of debt as a financing mechanism in this section. We conduct an experiment in which we compare the transitional dynamics of consumption tax-financed public spending with the dynamics when public spending is financed via debt, with a consumption tax used for debt servicing. The detailed analysis is available from the authors upon request.

We find that, apart from a strong progressive effect in the first period after the shock, debt financing does not smooth the distributional curves in the transition to the steady state, it even increases short-run variations. Furthermore, if debt is serviced by a consumption tax, long-run inequality is increased. This result hints at the fact that government bonds have a regressive effect, since we have shown in Section 3.1.3 that financing public spending via consumption taxes is distribution-neutral.

We limit ourselves to the reduced experiment described above, since a full-scale analysis of the equity and efficiency effects of government debt with all the model variations observed in Sections 3 and 4.1.1 would go beyond the scope of this article.[15]

4.2 Robustness

In this subsection we give further insights on the robustness of our results across theories and model assumptions (Subsection 4.2.1) and we summarize the results of an extensive sensitivity analysis (Subsection 4.2.2).

[14] Looking at a tax that increases output by 30%, as we did for capital, labor and consumption taxation in Section 3.2, only leads to a lump-sum tax of 0.0162% of output. For this tax level the distributional effects are not pronounced enough for displaying them graphically. We thus decided to rather fix the total amount of revenue to be raised and to set the lump-sum tax accordingly.

[15] Further interesting experiments would include relaxing the assumption that both middle and high income households have access to the same type of government bonds, or the assumption that debt is serviced after one period, investigating other channels for debt servicing, or considering the case of externally held debt (to exclude the capital accumulation-reducing effect of internally held debt).

4.2.1 Theoretical robustness

Our model is distinguished from previous work on the subject by assuming more sources of household heterogeneity: heterogeneous saving behavior (dynastic vs. life cycle), income sources and heterogeneous time preference rates. Although we believe that all these sources of heterogeneity are necessary to explain observed wealth disparities in industrialized countries (Cagetti and De Nardi, 2008; De Nardi and Yang, 2014), one may conclude that, from a theoretical point of view, this limits the scope of our analysis.

However, the major advantage of the structure of our model, combining an infinitely-lived with an overlapping generations agent, is great robustness in crucial modeling assumptions: While our main results are formulated in a neoclassical growth framework, we demonstrate in Section 4.1.1 that the results for labor and capital tax financing also hold for the case of endogenous growth. Furthermore, our analysis is conducted with heterogeneous time preference rates across agents. They seem to be the empirically realistic case (Dynan et al., 2004; Green et al., 1996; Lawrance, 1991), but have not been considered in previous work on the subject. Identical time preference rates are just a special case, leading to no particular change in behavior in our model (in Section 4.2.2 we present the results of a numerical experiment on this).

Previous work on modeling household heterogeneity in a dynamic setting that focused on initial endowments only, either chose endogenous growth models, i.e. constant returns to accumulable factors, or limited itself to the analysis of the transition to the steady state. The reason is that in the neoclassical growth model (i.e. decreasing returns to accumulable factors) with heterogeneity only in initial endowments and no further assumptions, the long-run distribution is indeterminate, in the sense that every possible distribution of capital is consistent with the steady state (Becker, 2006).[16] Heterogeneous time preference rates in the neoclassical model however lead to a steady state in which the agent with the lowest time preference rate owns all capital in the long-run, while less patient agents immediately consume all of their income and thus lead a "working poor" existence (Becker, 1980, 2006). We are only aware of one article that analyzes the case of heterogeneous time preference rates in an endogenous growth model, but this article has a somewhat different focus: Angyridis (2015) analyzes the equity and growth impacts of budget-neutral fiscal policy reforms when the government has access to non-linear income taxes. This discussion is summarized in Table 6.

To summarize, our model is both narrower (in the sense that more assumption on heterogeneity are made) and broader (in the sense of more robustness across growth theories) depending on one's viewpoint, when compared to previous work. Whether one considers this an improvement depends on whether one views the further assumptions on household heterogeneity as increasing realism (while maintaining modeling flexibility) or as needlessly sacrificing parsimony. In any case, the previous discussion shows that our model does not

[16]Chatterjee (1994) points out that in the case of imperfect capital markets, in which each household invests in its privately owned firm, the distribution in the long run would be completely equal, since capital poor agents would get higher rates of return on capital. This is also the mechanism behind the long-run outcome in Glomm and Ravikumar (1994). Chatterjee (1994) furthermore demonstrates that assuming perfect capital markets can also lead to a determinate steady-state distribution, if households are assumed to have consumption levels above a positive minimum threshold (which leads to different savings rates across households).

	Endogenous growth	Neoclassical growth
Identical ρ	Chatterjee and Turnovsky (2012) Alesina and Rodrik (1994)	Glomm and Ravikumar (1994) Section 4.2.2
Heterogeneous ρ	Angyridis (2015) Section 4.1.1	Section 3.1

Table 6: Selected literature on the equity and efficiency effects of public investment, with and without heterogeneity in the time preference rate ρ across households in neoclassical and endogenous growth models. Our contributions are indicated by the section numbers of this article. Note that in our model it is technically possible to also contribute to the first quadrant of this table (endogenous growth with identical time preference rates), but this experiment is excluded for brevity.

nest previous models but provides an independent alternative to exploring the impact of household heterogeneity on the effects of public investment.

4.2.2 Robustness across parameters

We find that our results from Section 3.1 do not change qualitatively in all of the scenarios described in Table 7. Furthermore, the results for capital and labor tax financing are very robust and are valid even beyond the parameter ranges given in this table. A detailed sensitivity analysis on which Table 7 is based is available from the authors upon request. The three most important results can be summed up as follows:

(i) For $\beta = 0$ a Pareto improvement is still possible even though the composite externality is only utility-enhancing. (ii) In the case of $\theta = 0$, in which the composite externality is only production-enhancing we also have the possibility of Pareto-improving policies. This means that our results do not depend on whether the composite externality affects production or utility, as long as it affects one of them positively. (iii) The results are robust in ε and φ which means that they also hold with a Romer (1986) and a Barro (1990) type of representation of the roles of public and private capital. Thus our assumption about household heterogeneity is the main driver of all observed effects.

Symbol	Parameter	Range
β	Exponent of $X_{p,t}$ in production	$[0, 0.4]$
(ε, φ)	Exponents in composite externality	$(0,1), (0.6, 0.6), (1, 0)$
l_h	Leisure high income household	$[0, 1]$
l_o	Leisure old middle income household	$[0.6, 1]$
$\rho_h = \rho_m$	Equal time preference rates (yearly)	1.2%
θ	Share of leisure in utility function	$[0.0, 3.5]$
σ_{Intra}	Intratemporal elasticity of substitution	$[0.6, 1.2]$
Standard CES utility $u_t = \left(\frac{1}{b}\right)\left((1-\theta)C_t^a + \theta(X_{u,t}l_t)^a\right)^{\left(\frac{b}{a}\right)}$, $\theta = 0.5$		

Table 7: Sensitivity analysis of the model. The character of the results does not change for these parameter variations.

5 Conclusion

The present article studies the effect of public investment on equity and efficiency. We introduce a concept of household heterogeneity that is based on stylized facts about empirical saving behavior and differences in income sources and time preference. We make two main contributions:

First, we find that in the long run, capital tax-financed public investment can enhance the total levels of wealth, welfare and income up to a certain tax rate and, at the same time, reduces inequality in these economic variables. Consumption tax financing also enhances productivity but leaves inequality in wealth, welfare and income virtually unaffected in the long run. This demonstrates that for these two financing mechanisms there is a tax range in which no equity-efficiency trade-off exists for the financing of public capital. We only find such a trade-off in case of labor tax financing since taxing labor income increases inequality but enhances the total levels of wealth, welfare and income (up to a certain level). We also compute the optimal tax levels for all three financing possibilities and find that agents differ in their preferred level. In sum, these results show that our assumptions about household heterogeneity lead to conclusions on the equity impacts of public investment that partially confirm and partially differ from previous work on the subject: Differences concern the case of consumption tax financing (for all inequality indicators) and capital tax financing, when wealth and welfare are considered as inequality indicators.

Second, the type of model examined in this article yields very robust results with regard to the modeling assumptions. The results neither depend on the assumption of homogeneous time preference rates across households nor on the assumption of endogenous growth.[17] Concerning the role of private and public capital in production, the results remain qualitatively the same if a Romer (1986), a Barro (1990) or an intermediate formulation is chosen, and they do not dependent on the dual role private and public capital play in productivity and utility, as long as it affects one of the factors positively.

We find that the equity and efficiency impacts of public investment are highly sensitive to the way heterogeneity is modeled. In the light of these findings, we agree with Diamond and Saez (2011), who, in a recent article on the policy relevance of modeling results, argue that "we should view with suspicion results that depend critically on very strong homogeneity or rationality assumptions" (p. 166). We thus conclude that a proper analysis of the equity and efficiency effects of public policies should take into account differences in household characteristics which are beyond initial endowments.

The modeling presented in this article could be extended to assess additional questions of public policy, for example climate policy, health spending or pension systems. A further refinement of the model structure could be to include mobility between income classes similar to García-Peñalosa and Turnovsky (2015), the transmission of human capital within families as in Becker and Tomes (1986) and the existence of public insurance schemes as, for instance, in Meijdam and Verbon (1997). Optimal policies could be derived by introducing an optimizing government with different welfare functions, in order to evaluate the implications of different welfare norms on equity and efficiency of the economy.

[17] Only the results for consumption tax financing are sensitive to the assumption of endogenous growth.

Acknowledgments

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Appendices

A Transitional dynamics for a labor and a capital tax

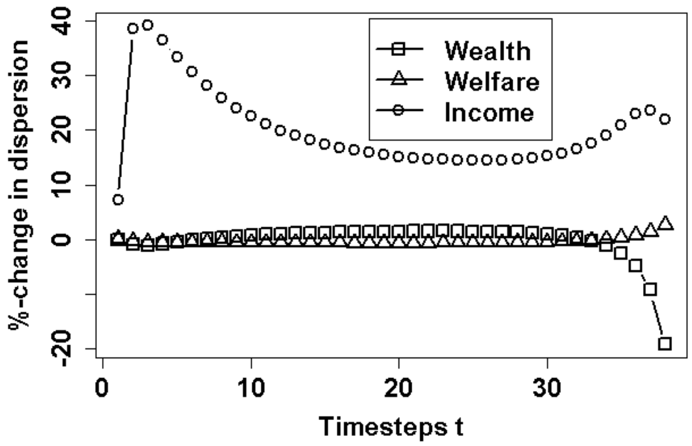


Figure 9: Transitory effects of an unanticipated increase of the labor tax from the baseline steady state to a new steady state. The new steady state has a 30 % higher output level than the baseline. Even though the long-term effect of labor tax-financed public investment is inequality-increasing, it decreases short-term wealth inequality.

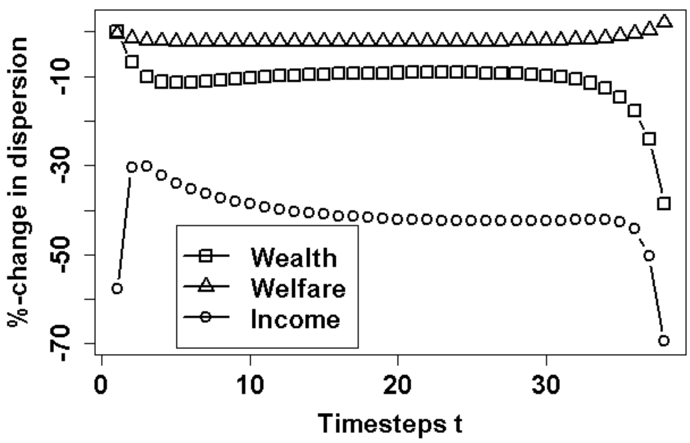


Figure 10: Transitory effects of an unanticipated increase of the capital tax from the baseline steady state to a new steady state. The new steady state has a 30 % higher output level than the baseline. For the case of capital tax financing, the model approximates the steady state monotonically, except for a strong first period decrease in income inequality, which can be attributed to the fact that middle income households choose their saving level in the period before the shock, whilst the high income households choose their level of saving already anticipating the shock.

B First-order conditions high income households

The Lagrangian of the optimization problem of the high income households can be written as:

$$\mathscr{L} = \sum_{t=0}^{t_{\text{final}}} u_t^{\text{ILA}} \cdot \frac{1}{(1+\rho_h)^t} + \lambda_t \left((1+(1-\tau_K)r_t)K_{h,t} + (1+\tau_c)C_t - K_{h,t+1} \right).$$

The first-order conditions of the high income household then are:

$$(1+(1-\tau_K)r_t)\lambda_t = \lambda_{t-1}, \tag{B.1}$$

$$\frac{\partial u_t^{\text{ILA}}}{\partial C_t} \cdot \frac{1}{(1+\rho_h)^t} = \lambda_t(1+\tau_c). \tag{B.2}$$

Calculating the derivations in Equation (7) yields the explicit Euler equation:

$$\frac{\left(C_{t-1}^a + \theta(X_{u,t-1}l_h)^a\right)^{\left(\frac{b}{a}-1\right)}}{\left(C_t^a + \theta(X_{u,t}l_h)^a\right)^{\left(\frac{b}{a}-1\right)}} \left(\frac{C_t}{C_{t-1}}\right)^{(1-a)} = \frac{1+(1-\tau_K)r_t}{1+\rho_h} \tag{B.3}$$

C First-order conditions middle income households

The Lagrangian of the optimization problem of the middle income household can be written as:

$$\mathscr{L} = u_t^{\text{OLG}} - \kappa_t \cdot \left(C_{y,t}(1+\tau_c) + \frac{(1+\tau_c)C_{o,t+1}}{(1+(1-\tau_K)r_{t+1})} - (1-\tau_w)w_t(1-l_t) \right).$$

The first-order conditions are calculated as:

$$\kappa_t = \frac{\partial u_t^{\text{OLG}}}{\partial C_{y,t}} \frac{1}{(1+\tau_c)} \tag{C.1}$$

$$\kappa_t = \frac{\partial u_t^{\text{OLG}}}{\partial C_{o,t+1}} \frac{(1+(1-\tau_K)r_{t+1})}{(1+\tau_c)} \tag{C.2}$$

$$(1-\tau_w)w\kappa_t = \frac{\partial u_t^{\text{OLG}}}{\partial l_{y,t}} \tag{C.3}$$

Combining Equations (C.1) and (C.2) we get the Euler equation (11). By combining (C.1) and (C.3) we get Equation (12). By calculating the partial derivatives of u_t^{OLG} and inserting them into Equation (11) and Equation (12) we get the explicit expressions:

$$\frac{C_{o,t+1}}{C_{y,t}} = \left(\left(\frac{1+(1-\tau_k)r_{t+1}}{(1+\rho_m)} \right) \cdot \left(\frac{C_{o,t+1}^a + \theta(X_{u,t+1}l_o)^a}{C_{y,t}^a + \theta(X_{u,t}l_{y,t})^a} \right)^{\left(\left(\frac{b}{a}\right)-1\right)} \right)^{\frac{1}{(1-a)}} \tag{C.4}$$

Here we can see that only the intertemporal decision given by Equation (C.4) is directly influenced by capital taxation, as this expression depends on τ_k.

$$\frac{l_{y,t}}{C_{y,t}} = X_{u,t}^{\frac{a}{(1-a)}} \left(\theta \cdot \frac{(1+\tau_c)}{(1-\tau_w)w_t}\right)^{\frac{1}{(1-a)}} \tag{C.5}$$

By contrast, we infer from the second Euler Equation (C.5) that the intragenerational labor-leisure decision is only directly influenced by consumption and labor taxation: the higher the labor or consumption tax, the higher the chosen levels of leisure.

D Steady-state equations of the economy

By formulating the equations for the system's steady state we can gain important insights about the main drivers of steady-state behavior. Additionally we can verify if the dynamic model, which is solved numerically, is solved correctly.

In the following all steady-state variables are denoted by a tilde. From Equations (6) and (14) it is easy to obtain an expression for the ILA's steady-state consumption $\tilde{C}$:

$$\tilde{C} = \rho_h \tilde{K}_h. \tag{D.1}$$

The middle income household's first-order conditions (Equations 9, 10, C.4 and C.5) and the first-order conditions of the firm (Equations 3 and 4) remain the same in the steady state.

The steady-state level of public capital $\tilde{K}_G$ is given by:

$$\delta_G \tilde{K}_G = \tau_K \cdot \tilde{r}\tilde{K} + \tau_w \cdot \tilde{h}\tilde{w} + \tau_c \cdot (\tilde{C} + \tilde{C}_y + \tilde{C}_o). \tag{D.2}$$

Together with the Equation (2) we have a system of partially nonlinear equations.

By combining the steady-state Equations (14), (D.1), (D.2) with the first-order conditions of the OLG agent (9, 10, C.4, C.5) and the firm (3 and 4), we can eliminate $\tilde{r}, \tilde{w}$ and $\tilde{C}$:

$$(1+\tau_c)\tilde{C}_y = (1-\tau_w)\left((1-\alpha)A\tilde{K}^{\alpha}\right)\tilde{X}_p^{\beta}(1-\tilde{l}_y)^{(1-\alpha)} - \tilde{S},$$

$$\tilde{C}_o = \frac{(1+\rho_h)}{(1+\tau_c)}\tilde{S},$$

$$\frac{\tilde{C}_o}{\tilde{C}_y} = \left(\left(\frac{1+\rho_h}{1+\rho_m}\right) \cdot \left(\frac{\tilde{C}_o^a + \theta(\tilde{X}_u l_o)^a}{\tilde{C}_y^a + \theta(\tilde{X}_u \tilde{l}_y)^a}\right)^{\left(\left(\frac{b}{a}\right)-1\right)}\right)^{\frac{1}{(1-a)}},$$

$$\frac{\tilde{l}_y}{\tilde{C}_y} = \tilde{X}_u^{\frac{2a-1}{(1-a)}} \left(\theta \cdot \frac{(1+\tau_c)}{(1-\tau_w)\left((1-\alpha)A\left(\frac{\tilde{K}}{(1-\tilde{l}_y)}\right)^{\alpha}\right)}\right)^{\frac{1}{(1-a)}},$$

$$\frac{\rho_h}{(1-\tau_K)} + \delta_K = \alpha A \left(\frac{(1-\tilde{l}_y)}{\tilde{K}}\right)^{1-\alpha} \tilde{X}_p^{\beta},$$

and

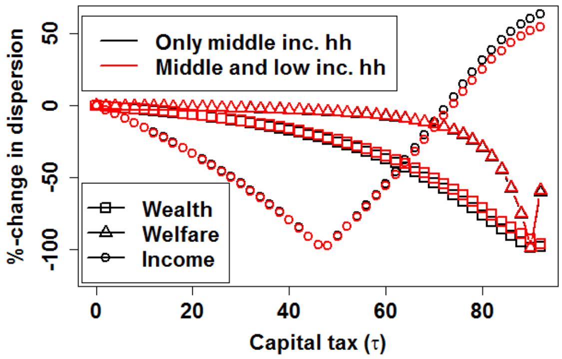
$$\delta_G \tilde{K}_G = \frac{\tau_K}{1-\tau_K} \cdot \rho_h \tilde{K} + \tau_w \cdot (1-\tilde{l}_y)(1-\alpha)A\left(\frac{\tilde{K}}{(1-\tilde{l}_y)}\right)^{\alpha} \tilde{X}_p^{\beta} + \tau_c \cdot (\rho_h \tilde{K}_h + \tilde{C}_y + \tilde{C}_o).$$

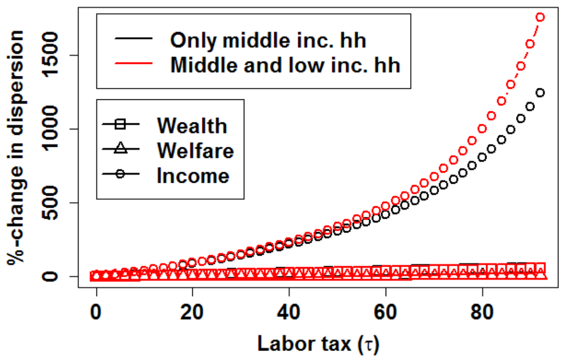
For the sake of readability we did not insert the expressions for $\tilde{K} = \tilde{K}_h + \tilde{S}$, for $\tilde{X}_p = \tilde{K}^{\varepsilon}\tilde{K}_G^{1-\varepsilon}$ and for $\tilde{X}_u = \tilde{K}^{\varphi}\tilde{K}_G^{1-\varphi}$. Now we only have a set of six partially non-linear equations in $\tilde{K}_h, \tilde{S}, \tilde{K}_G, \tilde{C}_y, \tilde{C}_o$ and $\tilde{l}_y$.

E Including the low income households

If low income households are included into the model calibration, 38 % of total net wealth is jointly owned by low and middle income households while 62 % is owned by high income households. This leads to a slight shift in the graphs on the distributional effects of public investment as displayed in Figure 11 (black lines depict the original calibration, red lines the calibration in which low and middle income households jointly own 38 % of the capital stock): For consumption tax financing hardly anything changes. However, the inequality-reducing effect of capital tax-financed public investment is weakened a little bit and the inequality enhancing effect of labor tax financing is increased.

We observe these effects since including the low into the middle income class means lower per capita wealth, welfare and income levels and thus an increased dispersion of these variables.





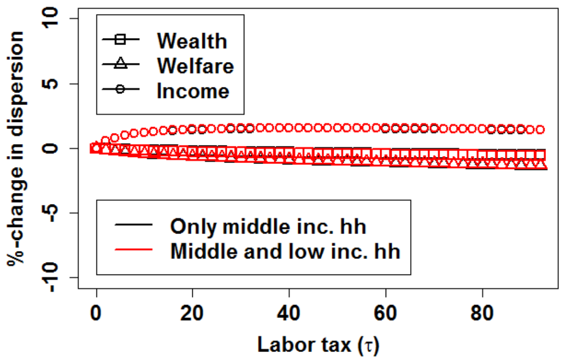


Figure 11: The distributional effects of public investment for capital tax (top), labor tax (middle) and consumption tax financing (bottom). The black lines are the results with the standard calibration, in which high income households (the top 5 %) own 62 % of total wealth and middle income households (the next 55%) own the remaining 38%. The case in which low and middle income households jointly own 38% of total wealth is displayed with red lines.

References

Alesina, A., Rodrik, D., 1994. Distributive Politics and Economic Growth. The Quarterly Journal of Economics 109(2), 465–490.

Angyridis, C., 2015. Endogenous Growth With Public Capital and Progressive Taxation. Macroeconomic Dynamics 19, 1220–1239.

Attanasio, O. P., 1994. Personal Saving in the United States. In: Poterba, J. M. (Ed.), International Comparisons of Household Saving, January, pp. 57–124, University of Chicago Press.

Barro, R. J., 1990. Government Spending in a Simple Model of Endogeneous Growth. Journal of Political Economy 98(S5), 103–125.

Becker, G. S., Tomes, N., 1986. Human capital and the rise and fall of families. Journal of Labor Economics 4(3), 1–39.

Becker, R. A., 1980. On the Long-Run Steady State in a Simple Dynamic Model of Equilibrium with Heterogeneous Households. The Quarterly Journal of Economics 95(2), 375–382.

Becker, R. A., 2006. Equilibrium dynamics with many agents. In: Dana, R.-A., Le Van, C., Mitra, T., Nishimura, K. (Eds.), Handbook on Optimal Growth 1. Discrete Time, pp. 385–442, Springer, Berlin, Heidelberg.

Browning, M., Lusardi, A., 1996. Household Saving: Micro Theories and Micro Facts. Journal of Economic Literature 34(4), 1797–1855.

Cagetti, M., De Nardi, M., 2008. Wealth inequality: Data and models. Macroeconomic Dynamics 12(S2), 285–313.

Calderón, C., Servén, L., 2014a. Infrastructure and inequality. In: Durlauf, S. N., Blume, L. E. (Eds.), The New Palgrave Dictionary of Economics. Online Edition., Palgrave Macmillan, Basingstoke, accessed: 1 December 2014.

Calderón, C., Servén, L., 2014b. Infrastructure and growth. In: Durlauf, S. N., Blume, L. E. (Eds.), The New Palgrave Dictionary of Economics. Online Edition., Palgrave Macmillan, Basingstoke, accessed: 1 December 2014.

Carroll, C. D., 2000a. Requiem for the Representative Consumer? Aggregate Implications of Microeconomic Consumption Behavior. American Economic Review 90(2), 110–115.

Carroll, C. D., 2000b. Why Do the Rich Save So Much? In: Joel B. Slemrod (Ed.), Does Atlas Shrug? The Economic Consequences of Taxing the Rich, pp. 465–84, Harvard University Press.

Chatterjee, S., 1994. Transitional dynamics and the distribution of wealth in a neoclassical growth model. Journal of Public Economics 54, 97–119.

Chatterjee, S., Ghosh, S., 2011. The Dual Nature of Public Goods and Congestion: The Role of Fiscal Policy Revisited. Canadian Journal of Economics/Revue canadienne d'Economique 44(4), 1471–1496.

Chatterjee, S., Turnovsky, S. J., 2012. Infrastructure and Inequality. European Economic Review 56, 1730–1745.

De Nardi, M., Yang, F., 2014. Bequests and Heterogeneity in Retirement Wealth. European Economic Review 72, 182–196.

Diamond, P., Saez, E., 2011. The Case for a Progressive Tax : From Basic Research to Policy. Journal of Economic Perspectives 25(4), 165–190.

Diaz-Gimenez, J., Glover, A., Rios-Rull, J.-V., 2011. Facts on the Distributions of Earnings, Income, and Wealth in the United States: 2007 Update. Federal Reserve Bank of Minneapolis Quarterly Review 34(1).

Dynan, K. E., Skinner, J., Zeldes, S. P., 2004. Do the Rich Save More ? Journal of Political Economy 112(2), 397–444.

Gale, W. G., Scholz, J. K., 1994. Intergenerational Transfers and the Accumulation of Wealth. Journal of Economic Perspectives 8(4), 145–160.

García-Peñalosa, C., Turnovsky, S. J., 2015. Income Inequality, Mobility, and the Accumulation of Capital. Macroeconomic Dynamics 19, 1332–1357.

Glomm, G., Ravikumar, B., 1994. Growth-Inequality Trade-Offs in a Model with Public Sector R& D. Canadian Journal of Economics/Revue canadienne d'Economique 27(2), 484–493.

Green, L., Myerson, J., Lichtman, D., Rosen, S., Fry, A., 1996. Temporal Discounting in Choice Between Delayed Rewards : The Role of Age and Income. Psychology and Aging I, 79–84.

Guvenen, F., 2006. Reconciling conflicting evidence on the elasticity of intertemporal substitution: A macroeconomic perspective. Journal of Monetary Economics 53(7), 1451–1472.

Krusell, P., Smith, A. A., 1998. Income and Wealth Heterogeneity in the Macroeconomy. Journal of Political Economy 106(5), 867–896.

Lawrance, E. C., 1991. Poverty and the Rate of Time Preference : Evidence from Panel Data. Journal of Political Economy 99(1), 54–77.

Mattauch, L., Edenhofer, O., Klenert, D., Bénard, S., 2016. Distributional effects of public investment when wealth and classes are back. Metroeconomica 67(3), 603–629.

Meijdam, L., Verbon, H. a. a., 1997. Aging and Public Pensions in an Overlapping Generations Model. Oxford Economic Papers 49, 29–42.

Michl, T. R., 2009. Capitalists, Workers, and Fiscal Policy. Harvard University Press.

Pasinetti, L. L., 1962. Rate of profit and income distribution in relation to the rate of economic growth. The Review of Economic Studies 29(4), 267–279.

Quadrini, V., 1997. Understanding the U . S . Distribution of Wealth. Federal Reserve Bank of Minneapolis Quarterly Review 21(2), 22–36.

Ray, D., 1997. Development Economics. Princeton University Press.

Romer, P. M., 1986. Increasing Returns and Long-Run Growth. Journal of Political Economy 94(5), 1002–1037.

Stiglitz, J. E., 1969. Distribution of Income and Wealth Among Individuals. Econometrica 37(3), 382–397.

Stiglitz, J. E., 2015. New Theoretical Perspectives on the Distribution of Income and Wealth among Individuals Part II: Equilibrium Wealth Distributions. NBER Working Paper Series 21190.

Turnovsky, S. J., 1997. Fiscal Policy in a Growing Economy with Public Capital. Macroeconomic Dynamics 1, 615–639.

Wolff, E. N., 1998. Recent Trends in the Size Distribution of Household Wealth. Journal of Economic Perspectives 12(3), 131–150.

Wolff, E. N., 2010. Recent Trends in Household Wealth in the United States: Rising Debt and the Middle-Class Squeeze – an Update to 2007. The Levy Economics Institute Working Paper Collection .

Chapter 7

Is capital back? The role of land ownership and saving behavior.[1]

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Is capital back?
The role of land ownership and saving behavior.

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Abstract

Wealth inequality is one of the major political concerns in most OECD countries. Under this premise we analyze different policy instruments in terms of their impact on wealth inequality and output. We use a general equilibrium model in which we disaggregate wealth in its capital and land components, and savings in their life-cycle and bequest components. Households are heterogeneous in their taste for the 'warm glow' of leaving bequests. We show that a government has considerable freedom in reducing wealth inequality without sacrificing output: A land rent tax enhances output due to a portfolio effect and reduces wealth inequality slightly. The bequest tax has the highest potential to reduce inequality, and its effect on output is very moderate. By contrast, we confirm the standard result that a tax on capital income reduces output strongly, and show that it only has moderate redistributive effects. Furthermore, we analyze different revenue recycling options and find that lump-sum recycling of the tax revenue to the young generation enhances output the most and further reduces wealth inequality.

JEL Classification: D31, E62, H23, H24, Q24

Keywords: Fiscal policy, wealth distribution, economic dynamics, bequests, land rent tax

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1 Introduction

In many OECD countries wealth-to-income ratios are rising (Piketty and Zucman, 2014) and inequality is relatively high, which is a matter of concern to policy makers. Saez and Zucman (2015) for instance find that the US wealth concentration is high by international standards and has considerably increased in recent decades. To counteract the concentration of wealth Benhabib et al. (2011) and Piketty and Saez (2013)[1] recommend taxes on capital. However, capital taxes discourage investment and reduce economic growth. Further, these authors do not distinguish between capital and wealth (Homburg, 2015), which is inconsistent with empirical findings as Stiglitz (2015) points out. In particular, Stiglitz highlights the fundamental role of land rents for the distribution of wealth.[2] Therefore, we compare taxes on capital income, land rents, and bequests in an overlapping generations model in which we disaggregate wealth into capital and land.

We show that governments have considerable freedom in reducing wealth inequality without sacrificing output. There is a range of combinations of land rent and bequest tax rates under which output remains unchanged, but public revenues and the wealth distribution can be varied.

Explicitly distinguishing the stocks of land and capital is crucial due to their inherently different dynamics. While capital is reproducible, land is fixed. The differing evolution of the capital and housing shares of wealth underline this point: In several developed economies, the increase of the wealth-to-GDP ratio in the post-WWII era is caused by an increase of the value of land (see, e.g., Homburg, 2015, Fig. 3).

In analogy to Piketty and Saez (2013), we choose preferences for bequests as the source of heterogeneity in our analysis. We do so since bequests are a key determinant of wealth inequality (Cagetti and De Nardi, 2008), and intergenerational transfers of wealth make up approximately half of total capital formation (Gale and Scholz, 1994), yet "theoretical implications of inequality in received inheritances are not yet fully understood and are likely to lead to arguments for positive taxation of bequests" (Kopczuk, 2013, p. 332).[3]

Next to Benhabib et al. (2011) and Piketty and Saez (2013) there are many other studies which analyze the distributional effects of taxation in heterogeneous agent models. Two classic papers on optimal taxation, Judd (1985) and Chamley (1986), establish that capital taxes are inefficient, and should not be used to redistribute wealth when households have heterogeneous preferences.

[1]Although Piketty and Saez (2013) is titled *A Theory of Optimal Inheritance Taxation*, the tax on bequests which they analyze is equivalent to a capital tax (p. 1854, Footnote 4). Accordingly, the title of their working paper version Piketty and Saez (2012) is *A Theory of Optimal Capital Taxation*.

[2]In contrast to Stiglitz (2015), Homburg (2015) seems to dismiss the distributional implications of the dynamics of land rent ownership in the conclusion of his article.

[3]We are aware of exceptions in the literature: In their empirical contributions Wolff and Gittleman (2014) and Bönke et al. (2015) find that bequests are not an important driver of wealth inequality. However, both studies do not take the top 1% of the wealth distribution fully into account. Further, the results of Wolff and Gittleman (2014) rest on the assumption that "(...) if wealth transfers are eliminated, there would be no effect on the saving behavior of those who have received transfers or are expecting them and that there would be no effect on the savings of those who intend to give a bequest." (p. 465). Due to the methodological difference from Wolff and Gittleman (2014) we are able to take exactly that counterfactual case into account in which transfers are eliminated and households actually change their saving behavior.

More recently, Chiroleu-Assouline and Fodha (2014) implement heterogeneity through differences in skill among workers. They find that if capital taxes (interpreted in their analysis as environmental taxes) are regressive, a complementary change of the income tax rules is Pareto efficient and renders the tax system progressive again.

To our knowledge, the only other study with heterogeneous agents that takes land into account apart from ours is Stiglitz (2015). However, the author takes only the polar case of two types of households into account: workers, who save only for consumption during their own old age, and capitalists, who save only to leave bequests to their offspring. He finds that taxing capital income cannot reduce wealth inequality since the capitalists always shift the tax burden to workers.

By contrast, we model heterogeneity in greater detail. We let different households have both savings motives, but to differing degrees. Thus, our framework is flexible enough to be calibrated to the empirical data on the distribution of wealth compiled by the OECD (2015). Due to our assumptions of endogenous saving and bequest heterogeneity instead of class membership, a capital income tax in our model reduces inequality in wealth.

We show that in fact all three instruments considered in our study reduce wealth inequality. However, they differ strongly in their effect on output (and thus also households' incomes). Taxing capital income has a negative effect on output levels for two reasons: The tax reduces households' incentive to save in general, but it also shifts investments away from capital towards land – a macroeconomic portfolio effect. Conversely, land rent taxation shifts private savings and investments away from land and towards capital, thereby enhancing output.[4] Bequest taxes do not affect the composition of the households' portfolio, so they have a significantly smaller effect on output. For the benchmark calibration, bequest taxes reduce output slightly. In that case, the reduction of income is stronger than the increased demand for leaving bequests. In other words, the income effect dominates the substitution effect. In the robustness analysis of our results, however, we also discuss cases in which the opposite is true, and bequest taxes slightly increase output.

Further, the saving behavior of households determines the redistributive effect. Each of the three tax instruments discourages savings to a certain extent, and thus also reduces bequests to the following generation. Since wealthy households' income consists of a relatively high amount of bequests, a reduction of the latter decreases their income more strongly than that of poorer households. The potential to redistribute wealth using land rent and capital income taxation is only moderate compared to bequest taxes, which directly target the source of inequality. Once all land rents are taxed away, or capital investments are choked, respectively, no further redistribution of wealth is possible.

Finally, different ways of recycling tax revenues to the economy have different impacts. Using the tax revenues to finance infrastructure investments

[4]Feldstein (1977) was the first to identify the portfolio effect, which Petrucci (2006) later formalized in an OLG. Edenhofer et al. (2015) extend the analysis of the portfolio effect by introducing a social welfare function as benchmark for evaluating fiscal policy, in particular land rent taxes. The present paper focuses on the economic impacts of fiscal policy and does not consider a social welfare function. Nevertheless, we find that under land rent taxation the winners of the policy could theoretically compensate the losers. Thus, land rent taxation fulfills the Kaldor-Hicks criterion (see Appendix D).

only raises the steady state level of output, but does not change the distribution of wealth. If public revenues are instead recycled as lump-sum transfers to households, we find an impact both on output and on the distribution of wealth: The more a government directs the transfers to the young, the higher the level of output in the steady state will be and the more equal wealth will be distributed. Our finding thus gives support to the proposal of the stakeholder society (Ackerman and Alstott, 1999), also voiced by Corneo (2011), Atkinson (2015), and Edenhofer et al. (2015).[5]

The rest of the paper is structured as follows. In Section 2 we introduce a simplified version of our model with sequential generations. Here, we highlight the importance of endogenous prices to justify our choice of a deterministic model with complete markets – an approach which we understand as complementary to Piketty and Saez (2013) and Benhabib et al. (2011), who model individual households' rate of return on capital and the distribution of wealth as determined by stochastic processes. In Section 3 we introduce overlapping generations and land, and perform the policy instrument analysis which is central to our paper. Sensitivity and robustness of our results are tested in Section 4. Section 5 concludes.

[5]Inspired by the idea of the stakeholder society, the United Kingdom introduced Child Trust Funds in 2005, which were replaced by Junior ISAs in 2011.

2 A simple model of bequest heterogeneity

In the present section, we develop a simple model of bequest heterogeneity to explain fundamental mechanisms at work. In particular, we want to demonstrate the importance of the impact of taxes on the interest rate for the distribution of wealth. Land as a production factor and the life cycle savings motive are omitted here and will be introduced in the next section.

Our simple model is based on Acemoglu (2008). To the best of our knowledge, it is the most parsimonious model of an economy in which new generations enter the economy each period and leave bequests to the next generation.

In each period t a new generation arrives in the economy and the old generation leaves the economy. There are N different types of households in each generation, which differ in their preferences. Each type of household $i \in \{1,...,N\}$ lives for one period, during which it receives income $y_{i,t}$. It divides its income between consumption $c_{i,t}$ and bequests for the next generation $b_{i,t}$, which are taxed at the uniform rate τ_B. A household derives utility from consumption and the "warm glow" (Andreoni, 1989) of leaving net-of-tax bequests:

$$u_{i,t} = \log(c_{i,t}) + \beta_i \log(b_{i,t}(1-\tau_B)). \tag{1}$$

The budget equation is given by

$$y_{i,t} = w_t + (1 + R_t(1-\tau_K))b_{i,t-1}(1-\tau_B) = c_{i,t} + b_{i,t}, \tag{2}$$

where w denotes wage income, R is the rate of return on inherited wealth, that is, the bequests from the previous generation, and $0 < \beta_i < 1$ determines the preference for leaving bequests for the household of type i of the next generation $t+1$. We assume that capital does not depreciate after use,[6] and that the offspring of a household has the same preferences as its parents.[7] Households may have to pay taxes τ_K on capital income or taxes τ_B on the bequests they receive.

Production is given by a standard neoclassical production function in intensive form $f(k)$ that satisfies the usual conditions. Then, for the equilibrium wage rate we have,

$$w_t = f(k_t) - f'(k_t)k_t, \tag{3}$$

and

$$R_t = f'(k_t).$$

We assume that all bequests are invested in capital k used for production:

$$k_{t+1} = \frac{1}{N}\sum_i b_{i,t}.$$

[6] Assuming positive depreciation does not alter the results qualitatively.

[7] This simplifying assumption may be justified by recent findings on the determinants of intergenerational wealth transmission which suggest potential roles for intergenerational transmission of preferences (Black et al., 2015).

2.1 Basic properties

Households choose the levels of consumption and bequests in order to maximize their utility (1) subject to their budget equation (2). This yields the first-order conditions

$$b_{i,t} = \frac{\beta_i}{1+\beta_i} y_{i,t} = \varphi_i \Big(w_t + (1+R_t(1-\tau_K)) b_{i,t-1}(1-\tau_B) \Big) \quad \forall t, \tag{4}$$

where $i \in \{1,...,N\}$ and $\varphi_i := \frac{\beta_i}{1+\beta_i}$.

With (4) it is possible to deduce a condition on the curvature of the production function which ensures the existence of a steady state (see Appendix A). This condition is, for instance, fulfilled by CES-type production functions. Then, the steady state level of bequests is given by

$$b_i^* = \frac{w^* \beta_i}{1+\beta_i - \beta_i\big(1+R^*(1-\tau_K)\big)(1-\tau_B)}, \tag{5}$$

where asterisks denote steady state levels. Further, if a steady state exists, it follows directly from (5) that households with relatively high preference parameters β_i for bequests have higher steady state levels of bequests than households with relatively low preferences for bequests.[8]

2.2 Fiscal policy

We consider a linear tax on capital income or on bequests which is implemented in the first time period of the model and remains constant for the whole time horizon. The main aim here is to highlight that the impact of the tax on the interest rate is crucial for how the tax affects wealth distribution.

Lemma 1. *Assume a steady state exists (cf. Corollary A, Appendix A).*

1. *An increase in the bequest tax leads to a decrease in wealth inequality, if and only if*

$$\frac{\mathrm{d}R^*}{\mathrm{d}\tau_B} < -\frac{1+R^*(1-\tau_K)}{(1-\tau_K)(1-\tau_B)}. \tag{6}$$

2. *An increase in the capital income tax leads to a decrease in wealth inequality, if and only if*

$$\frac{\mathrm{d}R^*}{\mathrm{d}\tau_K} < \frac{R^*}{1-\tau_K}. \tag{7}$$

By a decrease in wealth inequality we understand a decreasing steady state bequest ratio b_i^*/b_j^* of households i and j whenever $\beta_i > \beta_j$ (i.e. household i has a higher preference for leaving bequest than household j).

Proof. Let $i,j \in \{1,...,N\}$ such that $\beta_i > \beta_j$ and thus $b_i^* > b_j^*$ holds. We define $\psi_i := 1+\beta_i - \beta_i\big(1+R^*(1-\tau_K)\big)(1-\tau_B)$. Using (5) it is straightforward to calculate whether a marginal increase of a tax increases or decreases the ratio of steady state bequest levels:

[8] In other words, if $\beta_i > \beta_j$ for $i,j \in \{1,...,N\}$, then $b_i^* > b_j^*$. To see this, note that $\frac{\mathrm{d}b_i^*}{\mathrm{d}\beta_i} > 0$ for constant w^* and R^*.

1. $\frac{\mathrm{d}}{\mathrm{d}\tau_B}\left(\frac{b_i^*}{b_j^*}\right) = \overbrace{\frac{\beta_i}{\beta_j}(\beta_i - \beta_j)\psi_i^{-2}}^{>0}\left[\left(1 + R^*(1-\tau_K)\right) + \frac{\mathrm{d}R^*}{\mathrm{d}\tau_B}(1-\tau_K)(1-\tau_B)\right]$

2. $\frac{\mathrm{d}}{\mathrm{d}\tau_K}\left(\frac{b_i^*}{b_j^*}\right) = \underbrace{\frac{\beta_i}{\beta_j}(\beta_i - \beta_j)\psi_i^{-2}(1-\tau_B)}_{>0}\left[\frac{\mathrm{d}R^*}{\mathrm{d}\tau_K}(1-\tau_K) - R^*\right]$

The intuition behind conditions (6) and (7) is that wages, which all households receive equally and which are linked to the interest rate R via equation (3), should not decrease too much. If conditions (6) or (7) hold, there is an upper bound for the marginal product of capital $f'(k)$, and thus a lower bound for the capital stock, output, and wages.

Our interpretation of the above lemma is that prices matter for a comprehensive policy instrument analysis. Any statement about the impact of taxes on the distribution of wealth should consider how the taxes affect factor prices endogenously. In Section 3 we will build on this insight to derive more precisely how taxes affect an economy with heterogeneous agents and land when prices are endogenous. Thereby, our study can be understood as complementary to Benhabib et al. (2011) and Piketty and Saez (2013), who assume that the interest rate is exogenously given.

Further note, that Lemma 1 alone does not make a statement whether it is possible to alter the ranking of households' steady-state levels of bequests by fiscal policy.

3 The role of land rents and saving behavior for the economic impact of fiscal policy.

We extend the analytical model described in Section 2 by introducing land and by assuming that agents live for two periods instead of only one. Thus, in each period there are two generations that overlap. We make this assumption to differentiate between the life-cycle savings motive and the savings motive for leaving bequests, and also in order to have a market for land, on which old households may sell their land to young ones. Land thus serves both as a fixed factor of production and an alternative asset for households' investments.

We first give a model description. Then, in Section 3.2, we show how taxes on capital income, land rents, and bequests affect output and the wealth distribution in the steady state, without taking the spending side into account. Finally, in Section 3.3, we consider different ways of using the public funds generated by fiscal policy.

3.1 Model

The economy consists of N different types of households, which differ with respect to their preferences and live for two periods. Further, there is one representative firm and the government. The different preferences of each type of households imply different levels of wealth. Similar to the analytical model of sequential generations in Section 2, we observe that also in the model with overlapping generations, higher preferences for bequests imply higher steady state levels of wealth. For the rest of the paper we set $N = 5$ and use the index i to identify the household belonging to the ith wealth quintile, where households are ordered from lowest to highest preferences for bequests. We assume that the offspring of a household has the same preferences as its parents. Further, we shall assume a finite time horizon, i.e. $t \in \{1,...,T\}$, where one time step represents a period of 30 years (one generation). All variables are stated in per capita terms.

3.1.1 Households

The utility of households is given by an isoelastic function with elasticity parameter η. It depends on their consumption when young $c^y_{i,t}$, consumption when old $c^o_{i,t+1}$, and net bequests left to their children $b_{i,t+1}(1-\tau_B)$, on which the government may levy bequest taxes.

$$u\left(c^y_{i,t}, c^o_{i,t+1}, b_{i,t+1}\right) = \frac{(c^y_{i,t})^{1-\eta} + \mu_i (c^o_{i,t+1})^{1-\eta} + \beta_i \left(b_{i,t+1}(1-\tau_B)\right)^{1-\eta}}{1-\eta} \tag{8}$$

For the parameters we assume that $\mu_i, \beta_i \in (0,1)$. Households maximize their utility subject to the following budget equations.

$$\begin{aligned} c^y_{i,t} + s_{i,t} &= w_t + b_{i,t}(1-\tau_B) \\ s_{i,t} &= k^s_{i,t+1} + p_t l_{i,t+1} \\ c^o_{i,t+1} + b_{i,t+1} &= (1 + R_{t+1}(1-\tau_K))k^s_{i,t+1} + l_{i,t+1}(p_{t+1} + q_{t+1}(1-\tau_L)) =: v_{i,t+1} \end{aligned}$$

In period t a young household i earns wage income w_t, receives bequests from the currently old generation, and pays taxes on the bequests. The household uses its income to consume or save. Savings $s_{i,t}$ can be invested in capital $k^s_{i,t+1}$ or land $l_{i,t+1}$, which are assumed to be productive in the next period and may be taxed at rates τ_K and τ_L, respectively. We assume that capital is the numeraire good and land has the price p. When households are old, they receive the return on their investments according to the interest rate R_{t+1}, the price of land p_{t+1}, and the land rent q_{t+1}. We define household wealth $v_{i,t}$ as the sum of the values of the stocks of capital and land, and also the returns to investments in these stocks. Old households use their wealth to consume or to leave bequests for the next generation.

The first-order conditions of the households' optimizations are given by

$$(c^o_{i,t+1})^\eta = \mu_i(1+R_{t+1}(1-\tau_K))(c^y_{i,t})^\eta \tag{9}$$

$$\beta_i(1-\tau_B)^{1-\eta}(c^o_{i,t+1})^\eta = \mu_i b^\eta_{i,t+1} \tag{10}$$

$$\frac{p_{t+1}+q_{t+1}(1-\tau_L)}{p_t} = 1+R_{t+1}(1-\tau_K). \tag{11}$$

Note that the no-arbitrage condition (11) can be reformulated as the discounted sum of future rents:

$$p_t = \sum_{i=1}^{T} \frac{\widetilde{q}_{t+1}}{\prod_{j=T-i+1}^{T}(1+\widetilde{R}_{t+j})},$$

where $\widetilde{q}_t := q_t(1-\tau_L)$ and $\widetilde{R}_t := R_t(1-\tau_K)$, and we assume that in the final period T the price of land is zero, $p_T = 0$, since there is no following generation to buy the land. The no-arbitrage condition ensures that households invest in capital and land in such a way that the returns are equalized across the two assets. The returns are determined by the aggregate quantities of the input factors. Beyond this, the no-arbitrage condition does not impose any restrictions on how the asset portfolios of individual households are composed.[9]

3.1.2 Firm

The representative firm produces one type of final good using capital k, land l and labor, where the latter two are assumed to be fixed factors. We assume that the production function is of CES type. In intensive form it is defined as

$$f(k_t) = A_0[\alpha k_t^\sigma + \gamma l^\sigma + 1 - \alpha - \gamma]^{\frac{1}{\sigma}},$$

where A_0 is total factor productivity and $\sigma = \frac{\varepsilon-1}{\varepsilon}$ is determined by the elasticity of substitution ε. The firm's demand for capital k_t equals the aggregate of capital that is supplied by households $k^s_{i,t}$. The clearing of factor markets is described by

$$k_t = \frac{1}{N}\sum_{i=1}^{N} k^s_{i,t} \quad \text{and} \quad l = \frac{1}{N}\sum_{i=1}^{N} l_{i,t}.$$

[9]We shall make use of the convention that all households choose the same asset composition. More precisely, in every period t there is an $X_t > 0$ such that $X_t = k^s_{i,t}/l_{i,t}$ for all $i \in \{1,\dots,N\}$. We use this convention because there is an infinite continuum of possible combinations of individual asset portfolio compositions of each household i which have no bearing on any of our results.

In each period the firm maximizes its profit, which we assume to be zero due to perfect competition. Thus, the first-order conditions are

$$f_k(k_t) = R_t \quad \text{and} \quad f_l(k_t) = q_t,$$

and wages are given by $w_t = f(k_t) - R_t k_t - q_t l$.

3.1.3 Government

The government levies taxes on capital income τ_K, land rents τ_L, or bequests τ_B. Throughout Section 3.2, we assume that public revenues g_t are used for public consumption which has no effect on the economy. In Section 3.3 we relax this assumption and analyze alternative recycling schemes.

$$g_t = \tau_K R_t k_t + \tau_L q_t l + \frac{1}{N} \sum_i \tau_B b_{i,t}.$$

3.2 The revenue side of fiscal policy

The heterogeneity in household preferences and the introduction of land as an additional factor of production yield complex results, which go beyond that which is analytically tractable. Thus, we solve the model numerically using GAMS (Brooke et al., 2005). The parameter values are chosen such that the level of output and the distribution of wealth in the steady state match recent OECD data on the distribution of wealth (OECD, 2015).[10] In the present section we focus on the revenue side of fiscal policy and assume that the public revenues are not used for a specific purpose.

3.2.1 The policy-option space of output, redistribution, and public revenue

We evaluate fiscal policy along three dimensions: Their impact on output, their consequences for the wealth distribution, and their potential to raise public revenue.

We summarize our main result in Figure 1. The graphs show the feasible combinations of output f^*, the Gini coefficient of the wealth distribution $\{v_i^*\}_{i=1,\ldots,5}$, and the magnitude of public revenues g^* in the steady state if only one of the three tax instruments is used at a time. If taxes are set to zero, per capita output is about 1 million US\$ per time step (30 years) and the Gini coefficient of the wealth distribution has a value of about 0.63. This point is marked by the intersection of the two dashed lines.

[10]For a description of the calibration procedure and parameter values, see Appendix B. The robustness of our results with respect to different parametrizations is assessed in Section 4.

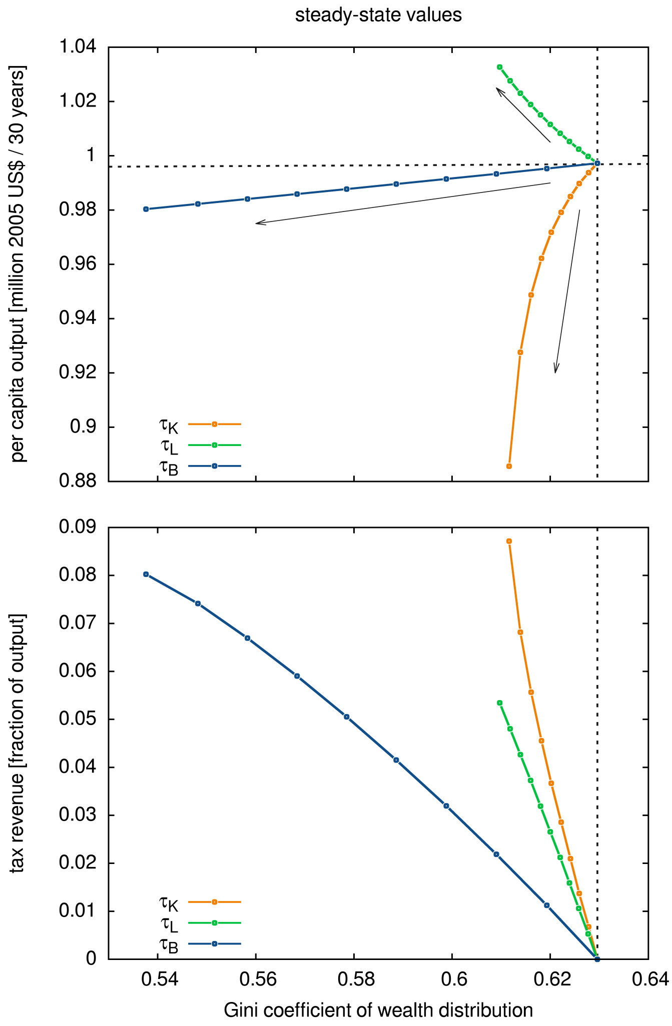

Figure 1: Depending on which tax instrument is used, the government may achieve different coordinates in the policy-option space of output, redistribution, and public revenue. Each curve represents the set of coordinates which are achievable with the use of one single tax instrument. The arrows in the upper panel indicate increases in the respective tax rate. The data points are chosen for tax rates in steps of 10%. They range from 0% to 100% for the land rent tax, and from 0% to 90% for the capital income and the bequest tax. Note that capital income and bequest tax rates of 100% produce extreme results which we have left out here for expositional reasons.

As the tax rates are increased above zero, respectively, we observe that all taxes reduce the Gini coefficient. Output increases under the land rent tax and decreases under the capital income tax. The bequest tax reduces output only slightly. Capital income and bequest taxes achieve higher public revenues than the land rent tax.[11]

The distribution of wealth depends on how fiscal policy affects the two components of the young households' income, i.e., wages and bequests. Rich households draw a higher proportion of their income from bequests than the

[11]In the robustness analysis of our results in Section 4.1.1, we will show that the potential to raise public revenues with the bequest tax crucially depends on the elasticity parameter η of households' utility function.

poor. When a tax affects the two sources of income differently, the distribution of wealth will change accordingly. It turns out that the capital income tax and the land rent tax reduce the after tax return to savings $1 + R^*(1 - \tau_K) = 1 + \frac{q^*}{p^*}(1 - \tau_L)$, which discourages savings and thus reduces bequests. Moreover, bequest taxes reduce households' income, and thus they also reduce bequests via the income effect. Households whose income consists of a comparably high share of bequests are affected more strongly by the bequest tax than households who receive most of their income as wages. As a consequence, each tax instrument reduces the income of richer households by a higher proportion than the income of poorer ones – all taxes have a progressive effect on the distribution of wealth (see Table 1).

	Household i	$\tau_K = 0.2$	$\tau_L = 0.2$	$\tau_B = 0.2$	$\tau_K = 0.7$	$\tau_L = 0.7$	$\tau_B = 0.7$
Income y^*							
	1	0.990	1.007	0.995	0.938	1.03	0.98
	2	0.990	1.007	0.995	0.938	1.03	0.98
	3	0.989	1.005	0.989	0.934	1.02	0.96
	4	0.987	1.003	0.975	0.925	1.01	0.91
	5	0.974	0.989	0.910	0.882	0.97	0.73
Bequests b^*							
	1	0.957	0.972	1.014	0.819	0.90	1.03
	2	0.957	0.972	1.014	0.819	0.90	1.03
	3	0.956	0.970	1.008	0.816	0.89	1.01
	4	0.954	0.968	0.994	0.808	0.88	0.97
	5	0.941	0.955	0.928	0.771	0.84	0.77

Table 1: Different tax instruments and rates imply different reductions in the steady state levels of income and bequests. We assume that only one tax is implemented at a time. The numbers give the respective fractions of the case in which no taxes are implemented. All tax instruments reduce the income and the received bequests of rich households by a greater fraction than that of poor households.

The level of output is influenced by households' choices on whether to invest in land or capital. Since land and labor are fixed, fiscal policy that stimulates (hampers) investment in capital will unambiguously increase (decrease) output. While a bequest tax only indirectly affects asset prices, taxes on capital income and land rents have a relatively strong impact. As the relative prices of assets change, households will react by changing the composition of their portfolio.[12] Since the tax on land rents shifts investment toward capital, output actually increases. The capital income tax has the exact opposite effect.

While the observed effects of land rent and capital income taxation are quite straightforward, the effects of the bequest tax are governed by the interplay of households' incomes and their substitution behavior. The immediate effect of increasing the bequest tax is to reduce households' income, which follows from the budget equations. A second immediate effect of bequest taxes is that they also increase demand for bequests relative to consumption in both periods of life, which follows from households' first-order conditions.

[12]For a graphical exposition of this fact, see Appendix C, Figure C.1.

Table 1 reveals that for relatively rich households the income effect outweighs the substitution effect, while for the poorer households the opposite is true. Since the bequest tax discourages the rich from saving for the purpose of leaving bequests, but encourages the poor to do so,it has a strong potential for wealth redistribution from the rich to the poor. With the bequest tax the Gini coefficient can, thus, be reduced to a significantly lower level than with the taxes on land rents or capital income.

The latter two have natural limits. Once all land rents are taxed away, there is no more scope for further tax increases and wealth redistribution. As capital income taxes are increased, investment in the main source of productivity is choked, and the economy collapses.

3.2.2 Output-neutral tax reform.

Figure 1 suggests that several combinations (τ_L, τ_B) of land rent tax and bequest tax rates can redistribute wealth while at least maintaining the same steady state level of output. In Figure 2 we show how the Gini coefficient changes under different combinations of bequest and land rent tax rates which do not reduce the steady state level of output below the level of the benchmark case in which $\tau_K = 0.2$, and $\tau_L = \tau_B = 0$. The assumed fixed capital income tax rate of 20% is roughly in line with the corresponding average tax rate in OECD countries.

It turns out that a typical OECD government has considerable freedom in choosing the desired value of the Gini coefficient without having to bear any costs in terms of forgone output. In our experiment, the Gini coefficient may be reduced from its benchmark value 0.63 down to almost 0.52, and public revenues increase from 1.4% to about 11% of output, as Table 2 shows.

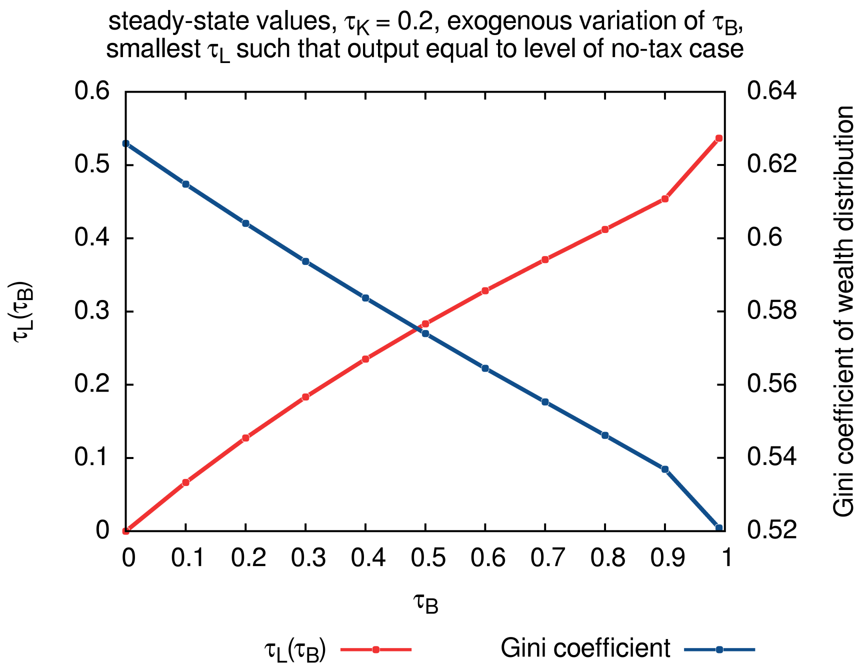

Figure 2: Combinations of bequest- and land rent taxes that imply the same steady-state level of output as in the benchmark case in which $\tau_K = 0.2, \tau_L = \tau_B = 0$.

τ_B	τ_L	Gini	public revenue per capita [10^3 2005 US$/30 years]	[fraction of output]
0.00	0.00	0.63	14	1.4%
0.10	0.07	0.62	28	2.8%
0.20	0.13	0.60	40	4.0%
0.30	0.18	0.59	52	5.3%
0.40	0.24	0.58	63	6.4%
0.50	0.28	0.57	73	7.4%
0.60	0.33	0.57	82	8.3%
0.70	0.37	0.56	91	9.2%
0.80	0.41	0.55	98	9.9%
0.90	0.45	0.54	105	10.6%
0.999	0.54	0.52	104	10.5%

Table 2: Combinations of bequest and land rent taxes that imply the same steady-state level of output ($f^* = 0.99$ million 2005 US$ / 30 years) as in the benchmark case in which $\tau_K = 0.2, \tau_L = \tau_B = 0$.

3.3 The spending side of fiscal policy

So far, we have only considered the revenue side of fiscal policy. Thereby we have assumed that the public revenues do not feed back into the economy. However, since public revenues are an endogenous variable and can become quite substantial, we now turn to the analysis of alternative uses of these revenues. Here, we show how different ways of recycling the revenues as lump-sum transfers to young and old households affect the policy-option space. In Section 4.2, we also consider the alternative case of productivity enhancing public spending, for example through infrastructure investments.

3.3.1 Lump-sum transfers to young and old households

We analyze the impacts of different transfer schemes by varying the distribution parameter $\delta \in [0, 1]$. Its value indicates the fraction of total transfers going to the old generation. Now, the budget equations of the young and the old households living in period t are given by

$$\begin{aligned} c^y_{i,t} + s_{i,t} &= w_t + b_{i,t}(1-\tau_B) + (1-\delta)g_t, \\ c^o_{i,t} + b_{i,t} &= (1 + R_t(1-\tau_K))k^s_{i,t} + l_{i,t}(p_t + q_t(1-\tau_L)) + \delta g_t. \end{aligned}$$

As Figure 3 shows, it makes a significant difference whether the government transfers the public revenues only to young households ($\delta = 0$), only to old households ($\delta = 1$), or to both[13]. The more the government directs transfers to the young, the higher the level of output in the steady state will be and the more equal wealth will be distributed.

If a transfer increases a young household's income, it directly increases consumption as well as savings (an income effect), and thus also capital supply and output. By contrast, a transfer to old households can in principle increase savings only indirectly. Through the direct income effect the old consume

[13]Here, we use $\delta = \frac{1}{2}$. In general, of course, any $0 < \delta < 1$ implies transfers to both.

more and leave more bequests. Leaving more bequests, as second-order effect, increases the income of the descendants. If bequests are taxed, then the second-order increase of the income of descendants is even smaller. However, it turns out that transfers to the old actually reduce savings through a substitution effect: Since young households anticipate the higher income in old age, they save less. The substitution effect is stronger for those households that have relatively low preferences for leaving bequests (and, thus, for savings). An overcompensation of the income effect through the substitution effect explains why the Gini coefficient increases and the output level decreases with δ.

It is worth mentioning that there is a relatively low threshold for the percentage of transfers which go to the old ($0 < \delta < 0.5$) above which the substitution effect is so strong, that steady state output falls below the case in which public revenues are not even fed back into the economy (see Appendix C, Figure C.3).

If the government uses the bequest tax, public revenues are highest under recycling scheme $\delta = 1$. The more transfers are directed to the young, the lower the bequest tax revenues become. Revenues from land rent and capital income taxes show no substantial change under variation of δ.[14] This difference is due to the fact that, unlike with the factor taxes, the choice of the redistribution parameter δ directly changes the tax base of the bequest tax.

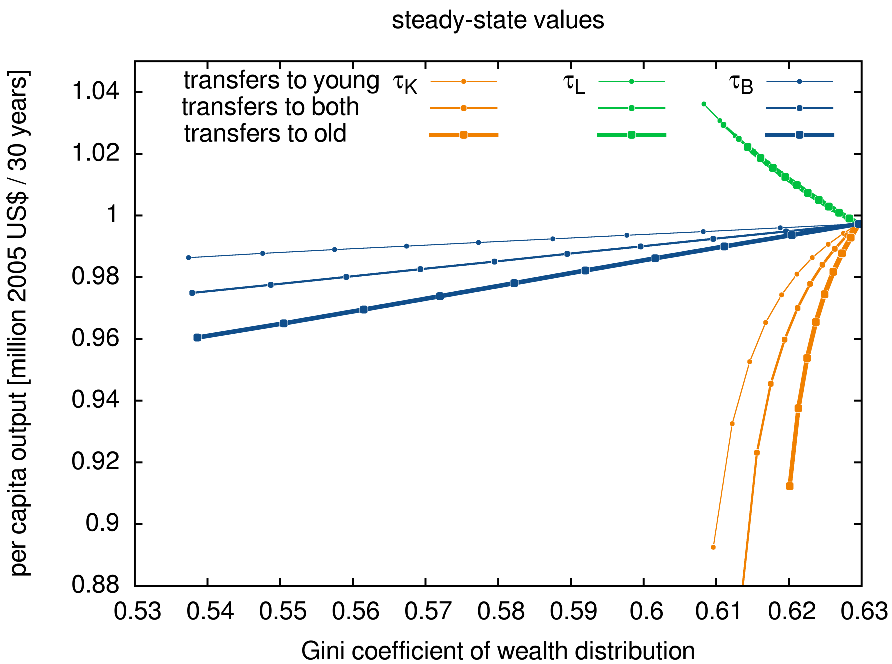

Figure 3: Impact of different recycling schemes on output and the distribution of wealth.

[14]See Appendix C, Figure C.2 for a graphical exposition of this fact.

4 Robustness checks and sensitivity analysis

This section shows the robustness of our main results with respect to different assumptions about model specifications. In Section 4.1, we describe how the policy option space (cf. Figure 1) changes under different parameter choices. Then, in Section 4.2, we discuss the alternative assumption that the government finances infrastructure investments with the tax revenues – instead of recycling them as lump-sum transfers.

4.1 Sensitivity analysis of the impacts of fiscal policy

We have calibrated the model parameters to match observed data on the distribution of wealth in OECD countries (OECD, 2015) under the assumption that the capital income tax rate τ_K is 20%, while land and bequests are not taxed – we shall refer to this as the standard policy case. To test the sensitivity of our results to the parameter choice, we have performed a one-at-a-time variation of all model parameters. For each variation of one specific parameter we have subsequently recalibrated all other parameters such that the standard policy case reproduces the observed data again.

For most tested parameters, we find that a variation has no significant qualitative nor quantitative effect on our results. However, the elasticity parameters of the utility function η and of the production function ε reveal a non-trivial relationship between parameter choice and model results. Thus, in the following we only present the results of separate variations of η and ε. Neither the simultaneous variation of the latter two parameters, nor simultaneous variations of multiple other randomly chosen parameters provided any further insights.

4.1.1 Utility function

The elasticity parameter of the utility function η has a significant impact on the distribution of wealth and, moreover, on output, even when taxes are not taken into account (see Figure 4). Ceteris paribus, the steady state level of output increases with η, while the Gini coefficient decreases. The reason is that households' substitution behavior depends on η. The first-order conditions (9) and (10) determine the relative demand for consumption and bequests. It turns out that higher values of η induce poorer households to save more, while it does not discourage rich households from leaving bequests significantly. Taken together, total wealth increases, in particular capital, and thus also output.

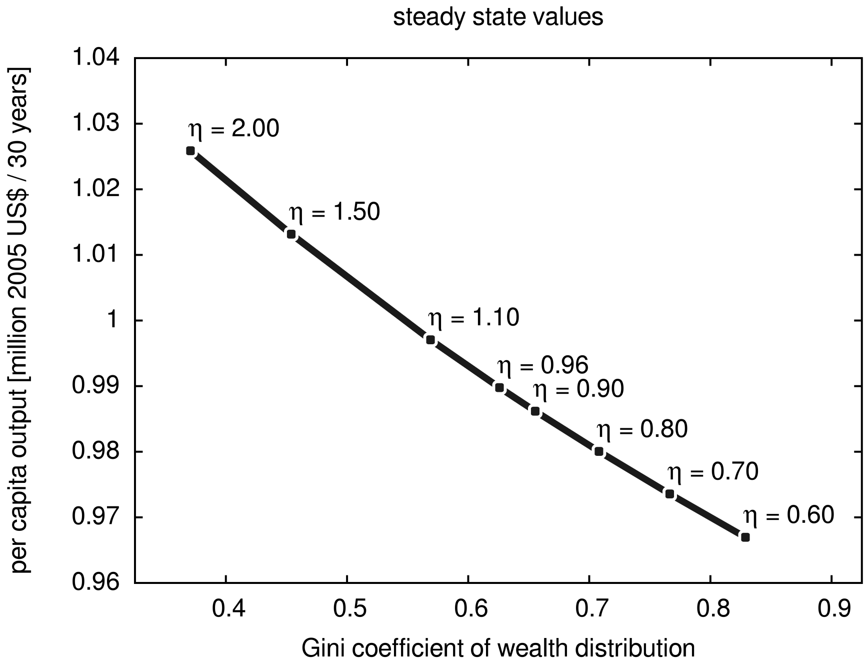

Figure 4: Variation of preference parameter η without recalibration to observed data. Benchmark case: $\eta = 0.96$.

Now, consider the parameter variation under recalibration of all other parameters. Figure 5 shows that the behavior of the economy in reaction to fiscal policy is sensitive to changes in the elasticity parameter. First, note that the potential to redistribute wealth with the capital income or the land rent tax increases with the elasticity parameter η. This is because increasing η implies that the tax-induced reduction in the after tax rate of return to savings $1 + R^*(1 - \tau_K) = 1 + \frac{q^*}{p^*}(1 - \tau_L)$ induces a stronger behavioral response. This means that for higher η, households reduce their savings more strongly in reaction to increases in capital income or land rent taxes. As discussed in Section 3.2.1, richer households' incomes are thus reduced by a higher factor than poorer households' incomes.

In contrast, the government's scope for wealth redistribution via the bequest tax decreases as η increases. The bequest tax is progressive due to the income effect it induces.[15] For higher values of η, however, the substitution effect gains in importance relative to the income effect, and thus, the bequest tax becomes less progressive.

[15]As explained in Section 3.2.1, rich households' income includes a higher proportion of bequests. Bequest taxes thus reduce their income by a higher factor than the incomes of poorer households.

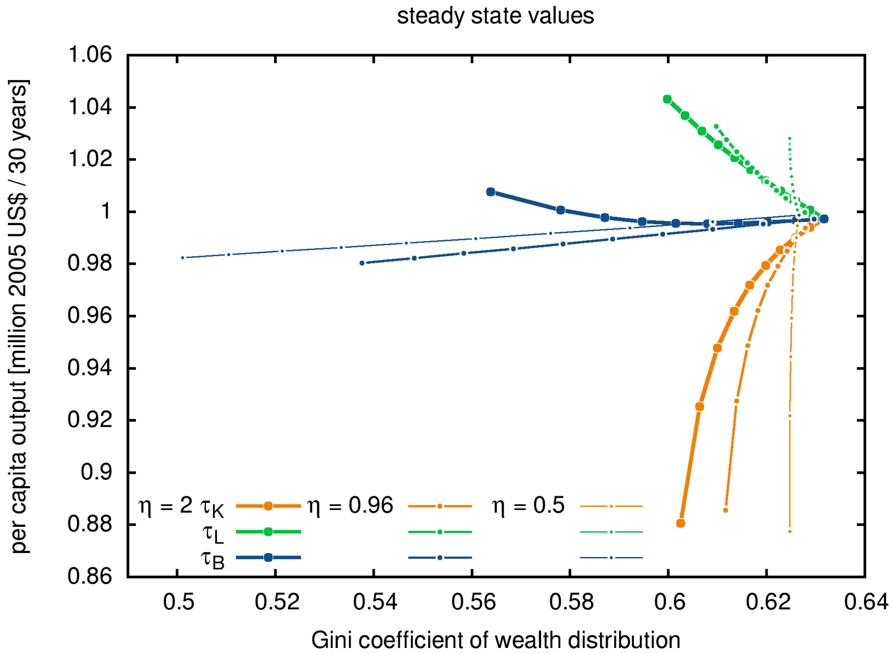

Figure 5: Policy-option space under variation of preference parameter η and subsequent recalibration of all other parameters such that the case of $\tau_K = 0.2, \tau_L = \tau_B = 0$ remains invariant under the variation of η.

Further, Figure 5 reveals that reactions to the bequest tax in terms of steady-state levels of output are qualitatively different for different values of η. When η is relatively high, the bequest tax has the tendency to increase output, in particular for higher tax rates. The opposite is the case for lower values. The variation illustrated in Figure 5 shows us how η determines the relative size of income and substitution effects of the bequest tax (see also the discussion in Section 3.2.1). For high η, the tax-induced substitution effect outweighs the income effect, households redirect their income away from consumption towards leaving bequests. Thereby they save more, which implies more capital, and thus a higher output level. For low η the opposite is the case.

Finally, in Figure 6 we see that the potential to raise public revenues with the bequest tax τ_B strongly depends on the choice of the elasticity parameter η. The higher η is, the greater the revenue raising potential of the bequest tax becomes. In contrast, revenues from capital income and land rent taxation remains almost unchanged when η changes.

The mechanism that drives this behavior is again the interplay of the income and substitution effects. For a high elasticity parameter η, the substitution effect outweighs the income effect. In that case, increasing the bequest tax also increases the demand for leaving bequests, and thus increases the tax base. In analogy, for low values of η, the opposite is the case.

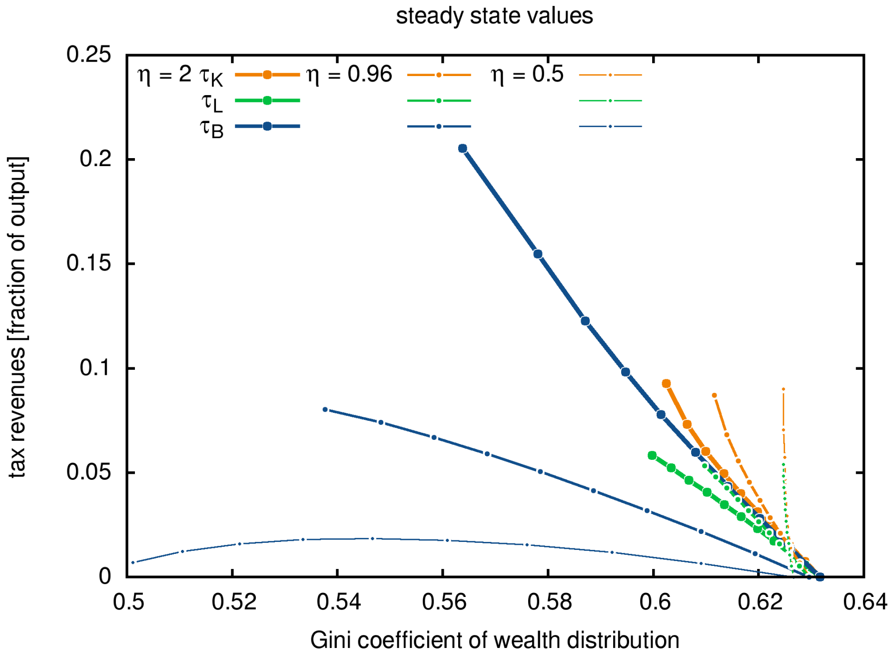

Figure 6: Tax revenues and Gini coefficient under variation of preference parameter η and subsequent recalibration of all other parameters such that the case of $\tau_K = 0.2, \tau_L = \tau_B = 0$ remains invariant under the variation of η.

4.1.2 Production function

Figure 7 shows that varying the substitution elasticity ε (and subsequently recalibrating all other parameters) has no greater qualitative impact. However, the graph shows clearly the intuitive result that varying the elasticity does change the results quantitatively. The higher the substitution elasticity is, the greater is the impact of bequest and capital income taxes on output and the wealth distribution. In contrast, the impact of land rent taxation on the wealth distribution is slightly reduced.

Varying ε changes the elasticity of capital supply with respect to capital income and bequest taxes. Hence, we observe a relatively strong increase in the impact of the two instruments if ε is increased. Since land is a fixed factor, changes in the effects of land rent taxation are much less pronounced when ε is varied.

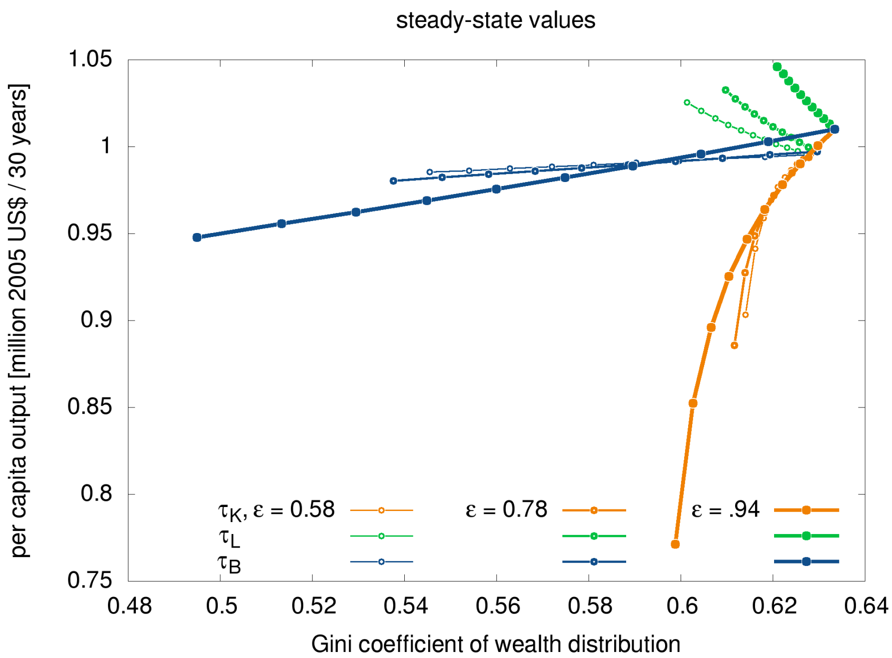

Figure 7: Policy-option space under variation of substitution elasticity ε and subsequent recalibration of all other parameters such that the case of $\tau_K = 0.2, \tau_L = \tau_B = 0$ remains invariant under the variation of ε. Benchmark case: $\varepsilon = 0.78$.

The elasticity of substitution determines the potential to raise public revenues in a similar way (see Figure 8 and Table 4 in Appendix C). Thus, the potential of the land rent tax remains invariant. Under relatively high values of ε, the bequest tax has a higher tendency to erode its tax base. Consequently, increasing ε reduces the tax revenues collected with the bequest tax. Finally, the capital tax also erodes its tax base more strongly under higher values of ε. However, the decrease of the capital stock k^* is less than the increase of the interest rate $R^* = f_k(k^*)$. Therefore, capital income tax revenues $k^*R^*\tau_K$ increase if the elasticity of substitution ε increases.

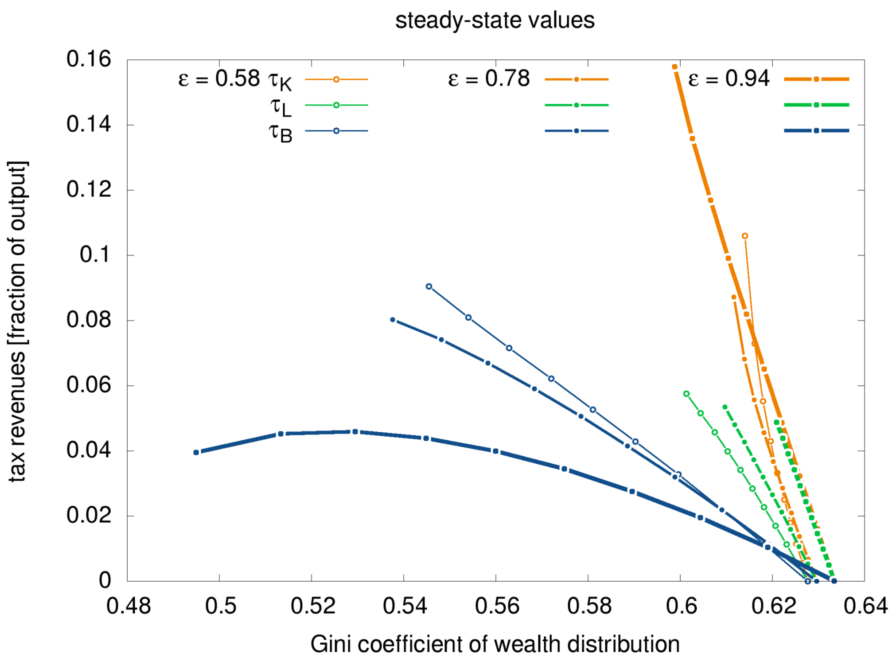

Figure 8: Tax revenues and Gini coefficient of wealth distribution under variation of substitution elasticity ε and subsequent recalibration of all other parameters such that the case of $\tau_K = 0.2, \tau_L = \tau_B = 0$ remains invariant under the variation of ε. Benchmark case: $\varepsilon = 0.78$.

4.2 Alternative spending option: Infrastructure investments

In Section 3.3 we considered different ways of recycling tax revenues as lump-sum transfers to the households. Here, we briefly show how results change under the alternative assumption that the government spends tax revenues to enhance firms' productivity, for example through infrastructure investments. In the following, we assume a simple linear relationship between public revenues and total factor productivity A:

$$A_t = A_0 + x_1 g_t$$

The impact of varying the efficiency parameter x_1 on output and the distribution of wealth are summarized in Figure 9. Independent of which tax instrument is used, an increase in the efficiency of public expenditures also increases the steady state level of output.

While output is quite sensitive to changes in x_1, the wealth distribution remains almost unchanged. The reason is that increasing x_1 raises incomes for all types of households equally. The so-caused increase in total factor productivity does not only increase wages, but also the return on savings. In sum, the incomes of all households increase by almost the same factor and the wealth distribution remains virtually unchanged.

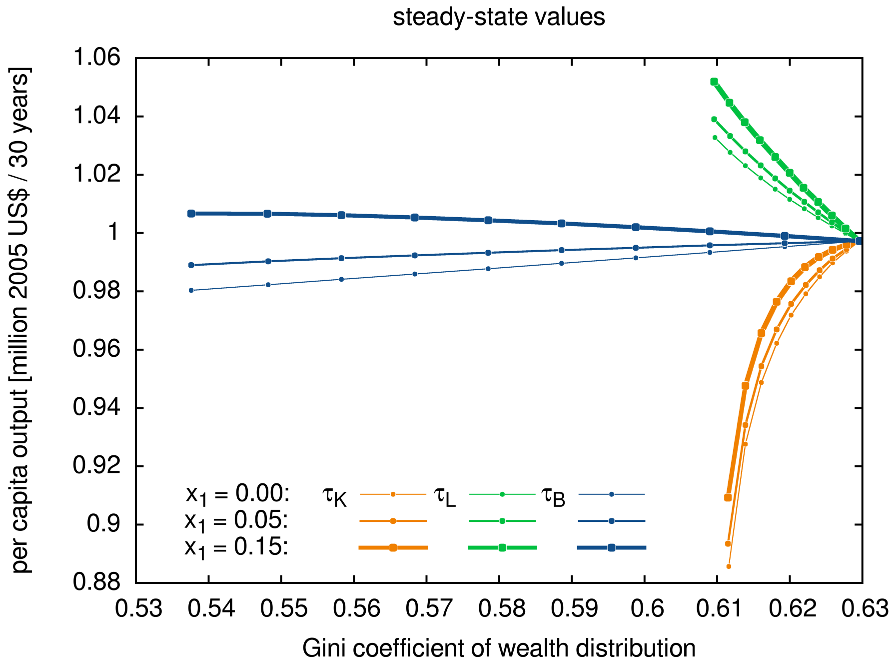

Figure 9: Impact of different degrees of effectivity of infrastructure on output and the wealth distribution

5 Conclusion

Is capital back? Thomas Piketty and Gabriel Zucman claim that this is the case by highlighting that the currently observed increased levels of inequality are due to a concentration of capital ownership at the top (Piketty, 2014, Piketty and Zucman, 2014). Recent literature, however, suggests that land ownership and bequest heterogeneity play a more important role in the process of wealth concentration (Homburg, 2015; Stiglitz, 2015; Cagetti and De Nardi, 2008). We illustrate this in an overlapping generations model that accounts for both features.

Our conclusions differ from Piketty's. Life-cycle saving (when invested in capital) should be left untaxed, while taxing bequests has a higher scope for redistribution at lower policy costs. Further, taxing the land rent component of wealth has a moderate scope for redistribution and strongly enhances output, due to a beneficial portfolio effect: Households shift investments away from the fixed factor land towards capital. The increase in capital investments directly increases output. Accordingly, capital income taxes reduce output since they discourage capital investments.

Atkinson (2015) takes up the idea of the stakeholder society (Ackerman and Alstott, 1999) and proposes, among other measures, to reduce inequality by endowing young households with a one-time transfer at adulthood. That transfer, according to Atkinson, should be financed by a wealth or inheritance tax. We demonstrate that financing such a transfer indeed reduces inequality. We find that the more the transfers are directed to the young and the less they are directed at the old, the higher output in steady state is and the more equal the wealth distribution is. In this case, reducing inequality goes hand in hand with enhancing output.

While heterogeneity in bequests is a key driver of the wealth distribution, it is not the only one which has been suggested by the literature. Entrepreneurial risk taking, income inequality, or the type of earnings risk at the top of the distribution (Cagetti and De Nardi, 2008; De Nardi, 2015), as well as differences in education (Pfeffer and Killewald, 2015) also may play an important role in determining the shape of the distribution and how it changes over time. The quantitative importance of each factor is still an open research question, and the design of tax policies crucially depends on its answer. Accordingly, our results will differ from findings based on other assumptions about the drivers of wealth inequality. Extending our analysis of policy instruments to a framework with multiple drivers of wealth inequality, as used for instance by De Nardi and Yang (2014), could yield valuable insights.

There is a further promising avenue for future research based on the present article. The policy instrument analysis conducted here has focused only on the impact of exogenously determined tax reforms on the steady state. It would be desirable to embed our analysis within a framework of optimal taxation and social welfare maximization, and thus combine the theory of optimal taxation with the literature on household heterogeneity.

Acknowledgements

We thank Mireille Chiroleu-Assouline, Robert C. Franks, Beatriz Gaitan, Linus Mattauch, Christina Roolfs, Gregor Schwerhoff, the participants of PIK's RD3 PhD seminar, and of the Potsdam Research Seminar in Economics for useful comments and fruitful discussions.

References

Acemoglu, D., 2008. Introduction to modern economic growth. MIT Press.

Ackerman, B., Alstott, A., 1999. The stakeholder society. Yale University Press.

Andreoni, J., 1989. Giving with impure altruism: applications to charity and Ricardian equivalence. The Journal of Political Economy pp. 1447–1458.

Atkinson, A. B., 2015. Inequality: What Can Be Done? Harvard University Press.

Benhabib, J., Bisin, A., Zhu, S., 2011. The Distribution of Wealth and Fiscal Policy in Economies With Finitely Lived Agents. Econometrica 79(1), 123–157.

Black, S. E., Devereux, P. J., Lundborg, P., Majlesi, K., 2015. Poor little rich kids? the determinants of the intergenerational transmission of wealth. Working Paper 21409, National Bureau of Economic Research.

Bönke, T., Corneo, G., Westermeier, C., 2015. Erbschaft und Eigenleistung im Vermögen der Deutschen: Eine Verteilungsanalyse. Discussion Papers 2015/10, Free University Berlin, School of Business & Economics.

Brooke, A., Kendrick, D., Meeraus, A., Raman, R., Rosenthal, R., 2005. GAMS – A Users Guide. GAMS Development Corporation.

Cagetti, M., De Nardi, M., 2008. Wealth inequality: Data and models. Macroeconomic Dynamics 12(S2), 285–313.

Chamley, C., 1986. Optimal Taxation of Capital Income in General Equilibrium with Infinite Lives. Econometrica 54(3), 607–622.

Chiroleu-Assouline, M., Fodha, M., 2014. From regressive pollution taxes to progressive environmental tax reforms. European Economic Review 69, 126–142.

Corneo, G., 2011. Stakeholding as a new development strategy for Saudi Arabia. Review of Middle East Economics and Finance 7(1), 1–19.

De Nardi, M., 2015. Quantitative Models of Wealth Inequality: A Survey. Working Paper 21106, National Bureau of Economic Research.

De Nardi, M., Yang, F., 2014. Bequests and heterogeneity in retirement wealth. European Economic Review 72(0), 182–196.

Edenhofer, O., Mattauch, L., Siegmeier, J., 2015. Hypergeorgism: When rent taxation is socially optimal. FinanzArchiv: Public Finance Analysis 71(4), 474–505.

Feldstein, M., 1977. The surprising incidence of a tax on pure rent: A new answer to an old question. The Journal of Political Economy 85(2), 349–360.

Gale, W. G., Scholz, J. K., 1994. Intergenerational Transfers and the Accumulation of Wealth. The Journal of Economic Perspectives 8(4), 145–160.

Homburg, S., 2015. Critical remarks on Piketty's Capital in the Twenty-first Century. Applied Economics 47(14), 1401–1406.

Judd, K. L., 1985. Redistributive taxation in a simple perfect foresight model. Journal of Public Economics 28(1), 59–83.

Kopczuk, W., 2013. Taxation of Intergenerational Transfers and Wealth. In: Auerbach, A. J., Chetty, R., Feldstein, M., Saez, E. (Eds.), Handbook of Public Economics, Volume 5, Newnes.

OECD, 2015. In It Together: Why Less Inequality Benefits All. OECD Publishing, Paris.

Petrucci, A., 2006. The incidence of a tax on pure rent in a small open economy. Journal of Public Economics 90(4), 921–933.

Pfeffer, F. T., Killewald, A., 2015. How rigid is the wealth structure and why? inter-and multigenerational associations in family wealth. Research Report 15-845, Population Studies Center.

Piketty, T., 2014. Capital in the 21st Century. Belknap Press.

Piketty, T., Saez, E., 2012. A theory of optimal capital taxation. Working Paper 17989, National Bureau of Economic Research.

Piketty, T., Saez, E., 2013. A theory of optimal inheritance taxation. Econometrica 81(5), 1851–1886.

Piketty, T., Zucman, G., 2014. Capital is Back: Wealth-Income Ratios in Rich Countries 1700–2010. The Quarterly Journal of Economics 129(3), 1255–1310.

Saez, E., Zucman, G., 2015. Wealth inequality in the united states since 1913: Evidence from capitalized income tax data. Technical report, Center for Equitable Growth, UC Berkeley.

Stiglitz, J. E., 2015. New Theoretical Perspectives on the Distribution of Income and Wealth among Individuals: Part III: Life Cycle Savings vs. Inherited Savings. Working Paper 21191, National Bureau of Economic Research.

Wolff, E. N., Gittleman, M., 2014. Inheritances and the distribution of wealth or whatever happened to the great inheritance boom? The Journal of Economic Inequality 12(4), 439–468.

A Mathematical tools

Here we develop some mathematical tools to analyze the simple model from Section 2.

Lemma A. *If there exists a period t' such that for all $i \in \{1,...,N\}$ it holds that $b_{i,t'} = b_{i,t'+1} > 0$, then there are b^* and k^* such that $k_{t'+l} = k^*$ and $b_{i,t'+l} = b_i^*$ $\forall l \geq 1$.*

Proof. Let t' be such that $b_{i,t'} = b_{i,t'+1}$ $\forall i$. Then it follows that

$$k_{t'+2} = \frac{1}{N}\sum_i b_{i,t'+1} = \frac{1}{N}\sum_i b_{i,t'} = k_{t'+1},$$

which implies $w_{t'+1} = w_{t'+2}$ and $R_{t'+1} = R_{t'+2}$. Using this we have

$$\begin{aligned}
b_{i,t'+2} &= \varphi_i\Big(w_{t'+2} + (1+R_{t'+2}(1-\tau_K))b_{i,t+1}(1-\tau_B)\Big)\\
&= \varphi_i\Big(w_{t'+1} + (1+R_{t'+1}(1-\tau_K))b_{i,t}(1-\tau_B)\Big)\\
&= b_{i,t'+1}.
\end{aligned}$$

The iteration of these two steps closes the proof.

□

Corollary A. *If the condition*

$$\lim_{k\to\infty} f''(k)(\beta_i f(k) - k) = 0 \tag{12}$$

holds for all i (e.g., when the production function is of CES- or Cobb-Douglas type), there exists a steady state with capital-labor ratio k^*, bequest levels $b_i^* = \frac{w^*\beta_i}{1-\beta_i R^*}$, and factor prices w^*, R^*.

Proof. Considering Lemma A we have to show that for some $t' \in \mathbb{N}$ the equations

$$b_i := b_{i,t'} = b_{i,t'+1} > 0, \quad i \in \{1,...,N\} \tag{13}$$

have a solution, respectively. To see this, we use Equation (4), which states that

$$b_{i,t'+1} = \varphi_i\Big(w_{t'+1} + (1+R_{t'+1}(1-\tau_K))b_{i,t}(1-\tau_B)\Big).$$

W.l.o.g. we assume that $\tau_B = 0 = \tau_K$. Plugging in Equation (13), we have

$$\begin{aligned}
& b_i = \varphi_i(w_{t'+1} + (1+R_{t'+1})b_i)\\
\iff \quad & b_i = \frac{\varphi_i w_{t'+1}}{1-\varphi_i(1+R_{t'+1})} \quad \forall i.
\end{aligned}\tag{14}$$

When Equation (13) holds, we always have $\varphi_i(1+R_{t'+1}) < 1$. This can be seen by using Equation (4), from which follows that

$$\begin{aligned} b_i = \varphi_i(w_{t'+1} + (1+R_{t'+1})b_i) &\iff (1+R_{t'+1})b_i\varphi_i = b_i - \varphi_i w_{t'+1}, \\ &\iff (1+R_{t'+1})\varphi_i = 1 - \underbrace{\frac{\varphi_i w_{t'+1}}{b_i}}_{>0} < 1. \end{aligned} \tag{15}$$

It remains to be shown that under condition (12) the Equations (14) have a solution. To see this, let's define

$$\psi(b_i) := \frac{\varphi_i w_{t'+1}}{1 - \varphi_i(1+R_{t'+1})}.$$

Due to constant returns to scale in the production function we have

$$\psi(b_i) = \varphi_i \frac{f(k_{t'+1}) - f'(k_{t'+1})k_{t'+1}}{1 - \varphi_i(1+f'(k_{t'+1}))}.$$

It is straightforward to calculate the first derivative of ψ with respect to b_i. Note that $k_{t'+1} = \frac{1}{N}\sum_j b_j$, so $\frac{\mathrm{d}}{\mathrm{d}b_i}k_{t'+1}(b_i) = \frac{1}{N}$. Thus it holds that

$$\psi'(b_i) = \underbrace{\frac{\varphi_i f''(k_{t'+1})}{(1 - \varphi_i(1+f'(k_{t'+1})))^2 N}}_{<0} \left[\varphi_i f(k_{t'+1}) - k_{t'+1}(1-\varphi_i)\right],$$

and

$$\psi'(b_i) \begin{cases} > 0\,, & \text{if } 0 > \varphi_i f(k_{t'+1}) - k_{t'+1}(1-\varphi_i) \\ = 0\,, & \text{if } 0 = \varphi_i f(k_{t'+1}) - k_{t'+1}(1-\varphi_i) \\ < 0\,, & \text{if } 0 < \varphi_i f(k_{t'+1}) - k_{t'+1}(1-\varphi_i) \end{cases}$$

Due to the monotonicity of the production function, there is only one non-zero value of $k_{t'+1}$ at which it is equal to $\frac{\varphi_i}{1-\varphi_i}f(k_{t'+1})$. Thus, as b_i increases from 0 on, ψ first falls monotonically, then reaches its minimum, and from then on increases monotonically. Depending on the values of the other b_j, $j \neq i$, the capital stock $k_{t'+1}$ could already be greater than $\varphi_i f'$ when $b_i = 0$. Now taking the limit of ψ', we see that

$$\lim_{b_i\to\infty} \psi'(b_i) = \lim_{b_i\to\infty} \frac{\beta_i}{N} f''(\beta_i f - k_{t'+1}).$$

So if Equation (12) holds, then ψ approaches some constant value. From Equation (15) we know that ψ is always positive. Thus, it must have at least one intersection with the function that maps b_i to itself, which is equivalent to the existence of a solution to Equation (14).

B Model parameters and calibration

To calibrate the model, we fix the steady state levels of output and wealth to average OECD data (OECD, 2015), the capital income tax rate at its approximate OECD average, and set the land rent and bequest tax rates to be zero. Then we solve for the parameters which describe household preferences and production technology. Table 3 summarizes these values.

The calibration algorithm is implemented as an optimization problem. More precisely, we find the preference and technology parameters by minimizing the weighted sum of the Euclidean norm of the differences between the OECD data and the steady state levels of output and wealth.

Preferences	Elasticity parameter	η	0.96
	Preferences for consumption when old	μ_1	0.070
		μ_2	0.070
		μ_3	0.095
		μ_4	0.152
		μ_5	0.468
	Preferences for leaving bequests	β_1	0.0001
		β_2	0.0001
		β_3	0.025
		β_4	0.082
		β_5	0.398
Production	Share parameter of capital	α	0.2
	Share parameter of land	γ	0.08
	Elasticity of substitution	ε	0.78
	Total factor productivity	A_0	481.9
Tax rates	Capital income tax	τ_K	0.2
	Land rent tax	τ_L	0
	Bequest tax	τ_B	0
Other	Time horizon	T	40

Table 3: Benchmark parameters that reproduce observed data on the wealth distribution in OECD countries.

C Additional figures and data

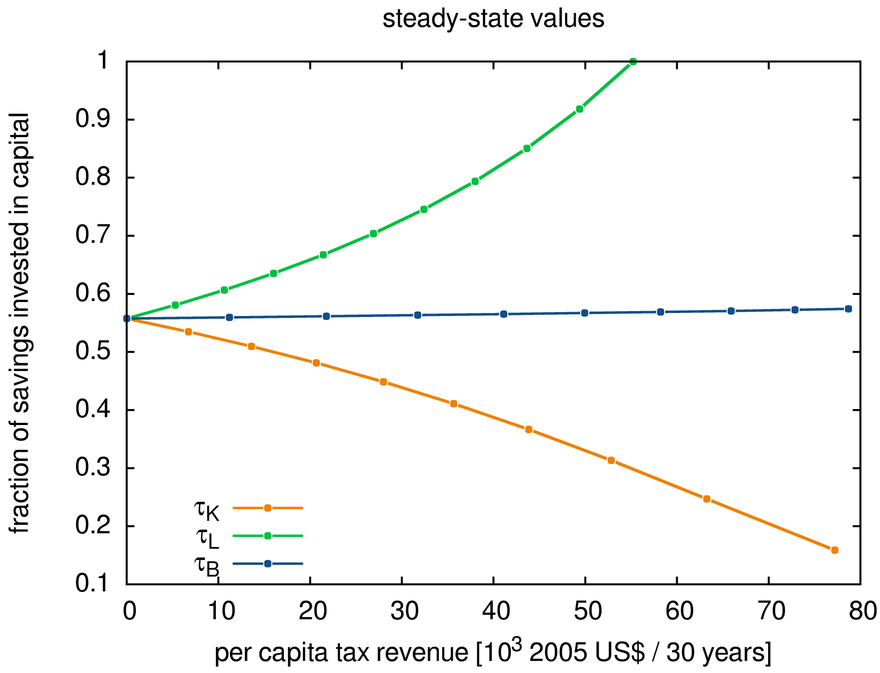

Figure C.1: Aggregate composition of assets (cf. Footnote 12) under variation of fiscal policy. Fiscal policy that stimulates (hampers) investment in capital will unambiguously increase (decrease) output. While a bequest tax only indirectly affects asset prices, taxes on capital income and land rents have a relatively strong impact. As the relative prices of assets change, households react by changing the composition of their portfolio. Since the tax on land rents shifts investment toward capital, output actually increases. The capital income tax has the exact opposite effect.

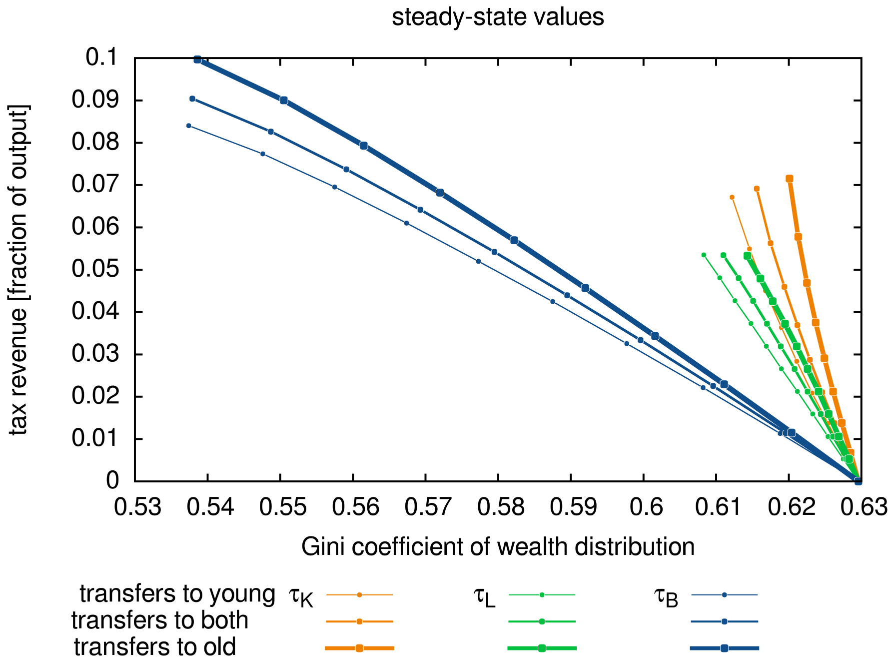

Figure C.2: The revenue raising potential of fiscal policy depends on the recycling scheme used. For all policy instruments, public revenues are higher the higher the share of transfers to the old. However, this effect makes a visible difference only in the case of the bequest tax τ_B. Figure 3 shows how the choice of the transfer scheme affects output.

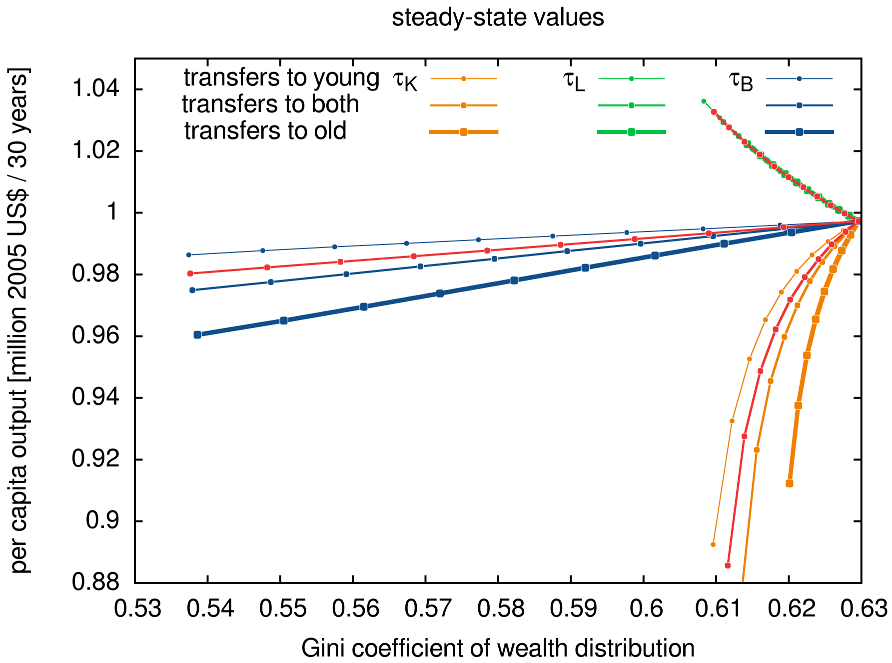

Figure C.3: Impact of different recycling schemes on output and on the wealth distribution (cf. Figure 3). The red lines mark the option space for the case in which public revenues are not redistributed.

	tax rate	tax revenue			output		
		τ_K	τ_L	τ_B	τ_K	τ_L	τ_B
$\varepsilon = 0.58$	0.2	11	6	22	990	999	993
	0.5	24	29	52	977	1007	990
	0.7	53	40	71	959	1013	987
$\varepsilon = 0.94$	0.2	32	10	19	990	1016	996
	0.5	78	25	39	947	1026	975
	0.7	105	35	44	896	1034	962

Table 4: Steady-state level of tax revenues and output per capita [10^3 2005 US$ / 30 years] for variation of substitution elasticity ε under subsequent re-calibration of all other parameters.

D Kaldor-Hicks criterion

Even though we find that recycling all public revenues to the young as lump-sum transfers enhances output and reduced inequality, a Pareto improvement is not possible. However, we find that at least there are cases in which the Kaldor-Hicks criterion is fulfilled. Consider, for instance, the case in which all land rents are skimmed off and redistributed to the young ($\tau_L = 1$, $\delta = 0$) shown in Figure D.4. Absent any additional transfer mechanism between winners and losers, the households belonging to the first old generation always bear the burden, except those in the lowest wealth quintile $i = 1$, whose utility does not change under the 100% land rent tax. Further, not only the first old generation, but in fact all generations belonging to the top wealth quintile $i = 5$ suffer under the tax.

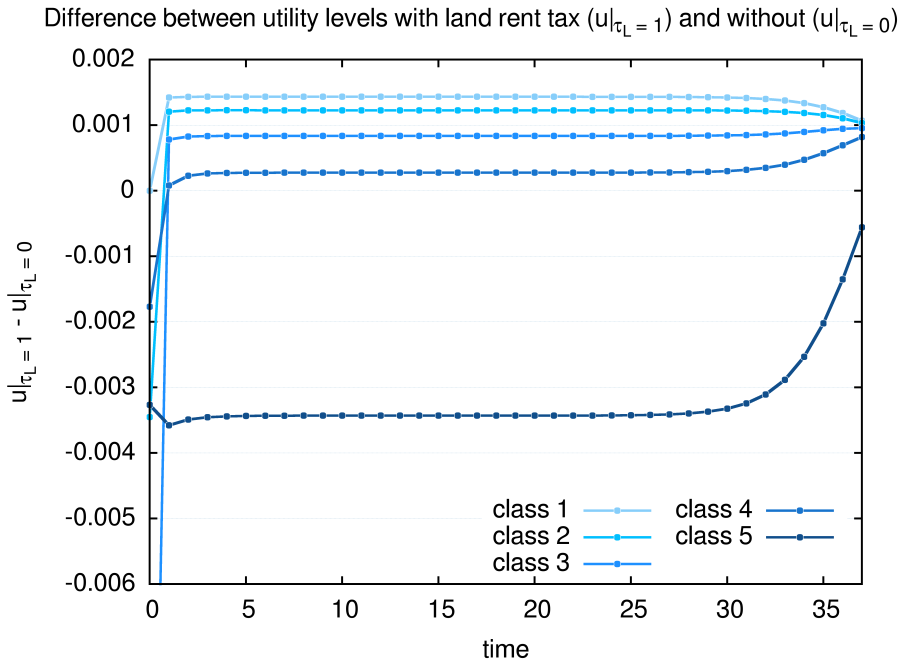

Figure D.4: When land rents are taxed at 100% and recycled as lump-sum transfers to the young, the first old generation and the richest households bear the burden. Their utility under taxation is less than without taxation, i.e., $u|_{\tau_L=1} - u|_{\tau_L=0} < 0$. All other households benefit from the policy.

Now, we introduce a mechanism which allows intertemporal transfers between households. Instead of the lump-sum transfers from public revenues g_t, young and old households may now receive a transfer or have to pay a lump-sum tax X. Their budget equations thus are

$$c^y_{i,t} + s_{i,t} = w_t + b_{i,t}(1 - \tau_B) + X^y_{i,t}$$
$$c^o_{i,t} + b_{i,t} = (1 + R_t(1 - \tau_K))k^s_{i,t} + l_{i,t}(p_t + q_t(1 - \tau_L)) + X^o_{i,t}.$$

Further, we assume that funds can be shifted over time via banking and borrowing at the market interest rate R. Then, for the total volume of the transfers it has to hold that

$$\sum_t \frac{g_t}{\Pi_{s=1}^t (1+R_s)} \geq \frac{1}{N} \sum_{i,t} \frac{X_{i,t}^y + X_{i,t}^o}{\Pi_{s=1}^t (1+R_s)}.$$

Our numerical experiments confirm that there are feasible combinations of $\{X_{i,t}^y, X_{i,t}^o\}_{i=1,\dots,N,\ t=1,\dots,T}$ such that the winners of the 100% land rent tax can compensate the losers, i.e., that

$$u_{i,t}|_{\tau_L=1} \geq u_{i,t}|_{\tau_L=0} \quad \forall i,t.$$

Chapter 8

Synthesis and outlook

This thesis is centered around the question whether political regulation of the use and supply of common goods can be designed such that it enhances equity. The point of departure of this thesis is that, in many developed countries, inequality has been rising over the last decades and that many common goods, which are vital for growth and welfare, are mismanaged.

This mismanagement of common goods, especially if they are available on a global scale, is often due to missing incentives. A major premise in standard economic theory is that efficiency and equity issues should be treated by separate policies. I argue that this premise, however, is rendered invalid in the presence of common goods, which represent a type of economic externality. Efficiency reasons are not enough to provide these goods at an optimal level on a global scale. However, designing policies for the regulation of common goods such that they also enhance equity provides additional incentives for a stricter common good policy.

I choose two common goods for the current analysis: the atmosphere, in its function as a sink for greenhouse gases, and infrastructure. I find these two examples most instructive, since each good represents one type of capital. The atmosphere is a natural capital stock which, in the absence of policy, is overexploited. Infrastructure, on the other hand, is a physical capital stock, which is underfunded in the absence of policy.

This final chapter reviews the results from the preceding chapters in Section 8.1. It discusses why analyzing different distributional problems require different models of households heterogeneity in Section 8.2. I further outline future research questions arising from possible extensions of the current work in Section 8.3. Finally, in Section 8.4, I answer the research questions raised in Chapter 1 and discuss the potential policy implications of the results derived in this thesis.

8.1 Summary of the results

This section summarizes the results from Chapters 2-7 and puts them in a common context.

8.1.1 Climate policy

The first common good that is studied in this thesis is the atmosphere. Until now the atmosphere can be used as a sink for greenhouse gases without high costs associated with it. Therefore, the atmosphere is used beyond its regenerative capacities, which leads to an increasing global mean temperature (more details on the physical science behind global warming can be found in Section 1.3).

The most efficient mechanism for reducing greenhouse gas emissions into the atmosphere is some form of emission pricing. Even though this fact is widely recognized, greenhouse gas emissions are priced at a very low rate in most countries (some countries even subsidize fossil fuels). The two major reasons for this mismanagement of the atmosphere are disagreements on the level and the distribution of the costs associated with ambitious emission pricing policy.

In particular, one argument which prevents ambitious emission pricing is that it would increase the gap between rich and poor households, since poor households spend a higher share of their income on carbon-intensive goods (Combet et al., 2010; Ekins, 1999). I analyze this argument in Chapter 2 in detail, by modeling a carbon-intensive subsistence level and heterogeneous households which differ in their earning abilities. The main finding is that a carbon tax can be progressive if it is combined with a mechanism that uniformly redistributes the carbon tax revenue to the households. If the tax revenue is used to cut each household's income tax by the same amount, the tax reform becomes regressive.

One simplifying assumption in Chapter 2 is that optimal taxes cannot be determined explicitly. As a consequence, it is not possible to determine the optimal revenue redistribution of carbon tax revenue. Furthermore, in Chapter 2 it is assumed that prices are constant. In Chapter 3 I therefore extend this framework to an optimal taxation model with endogenous prices. These extensions, however, require a numerical solution of the model. Two main results are derived: First, the income tax system can always adjust to an increase in the optimal carbon tax such that the tax reform is almost distribution-neutral, even if income taxes were already set at an optimal level before the carbon tax increase.[1] Second, I demonstrate in a calibrated model that, if the income tax system before the carbon tax reform is suboptimal, a carbon tax reform has the potential to significantly decrease inequality. I refer to this effect as the *double dividend of redistribution*.

Chapter 4 is concerned with the costs of ambitious climate policy, but also discusses the topics of intra- and intergenerational equity. In this chapter, dif-

[1] Such an increase in the optimal carbon tax can be induced by an increase in the preference for environmental quality.

ferent interactions between climate policy and fiscal policy are discussed. The focus lies on beneficial interactions that reduce the costs of climate policy. On the revenue raising side, it is shown how carbon pricing can reduce tax competition and, through inducing a shift in investors' portfolios, enhance capital accumulation. On the spending side, revenue from carbon pricing can be used to increase investment in public capital. The literature on the distributional effects of climate policy as well as the literature on the growth effects of inequality is discussed. It is examined if the regressive effects of carbon pricing can be offset by revenue-recycling and to what extent a carbon tax-financed increase in public spending might have the potential to reduce inequality. Finally it is argued that it is theoretically possible to design climate policy that constitutes an intergenerational Pareto improvement.

8.1.2 Infrastructure policy

The common good studied in Part II of this thesis is infrastructure. Infrastructure plays a crucial role determining the growth path of an economy but its provision also has positive distributional aspects. However, due to the common good nature of infrastructure, it tends to be undersupplied in the absence of policy. Furthermore, empirical evidence shows that, even with policies in place that regulate its provision, infrastructure is largely undersupplied in most parts of the world.

Infrastructure has a positive effect on growth but levying taxes for its financing tends to distort the economy and thus reduces growth.[2] The trade-off between these two effects generates the level at which infrastructure is supplied. Even though there seems to be empirical evidence that infrastructure investment might reduce inequality, the size of these effects and the mechanisms behind them are still relatively unclear. The purpose of Part II is to explore the different channels through which infrastructure financing acts on equity and efficiency and to compare different policy designs for increasing public investment in infrastructure.

Barro (1990) exemplifies the trade-off between the growth-enhancing effect of public capital and the distorting effect of its financing in a small model with one representative household. In Chapter 5, I analyze a similar trade-off in a heterogeneous households model in which public capital is financed by a capital tax. The concept of heterogeneity is based on stylized facts about heterogeneity in saving behavior, income sources and time preference rates. I reach three main conclusions: First, with heterogeneous households there is no clear cut trade-off anymore. Depending on their saving behavior, income source and time preference, different households prefer different tax rates. Second, financing public capital with a capital tax reduces wealth inequality. Third, such a policy is Pareto-improving for low tax rates.

In Chapter 6 the analysis from Chapter 5 is broadened in several aspects: inequality in wealth, as well as in income and in welfare is analyzed, more financing mechanisms such as labor and consumption taxation are considered,

[2]Under the premise that non-distortionary first-best lump-sum taxes and taxes on fixed factors such as land are unavailable to the government. Only in Chapter 7 I consider land rent taxation as a source of government income.

labor is made endogenous, public capital is modeled to affect both productivity and utility and more general functional forms are used. Due to the enhanced complexity the model is then solved numerically. The main conclusion from this chapter is that public capital can have a decreasing, neutral or increasing effect on inequality, depending on its financing. While financing it with a consumption tax hardly changes the distribution, labor tax financing increases and capital tax financing decreases inequality. All financing mechanisms enhance efficiency, at least for lower tax rates. However, labor and consumption taxation lead to a higher efficiency increase than capital taxes since they are less distortionary. In some of the earlier literature it is claimed that inequality in wealth and welfare is always increased by infrastructure investment, independent of its financing, and that consumption tax financing leads to increased inequality in wealth, welfare and income. The study presented in Chapter 6 demonstrates that this is not the case when heterogeneity in saving behavior, income sources and time preference is taken into account.

Two important determinants of the long-run wealth distribution are not mentioned in Chapters 5 and 6: Stiglitz (2015a,b) argues that fixed factors such as land and the rents derived from those factors are crucially influencing the recent increase in wealth inequality as described in Piketty (2014) and Piketty and Zucman (2014). The second determinant are intergenerational wealth transfers, especially bequests.

In Chapter 7, I hence disaggregate wealth into physical capital and land, and I distinguish between life-cycle and bequest savings. Households are assumed to differ in their preferences for leaving bequests. The government has access to taxes on land rents, bequests and physical capital (that is, life-cycle savings plus bequest savings). The main finding is that a combination of bequest and land rent taxes has the potential to greatly reduce wealth inequality without harming growth. This result is independent of the recycling of the revenues, which is either recycled via lump-sum transfers or through public investment.[3] The main driver behind this result is that the land rent tax is moderately progressive but enhances efficiency due to a beneficial portfolio effect. The bequest tax greatly reduces wealth inequality with only minor effects on total output – combining these two taxes hence leads to reduced wealth inequality without a reduction in output. This sheds new light on the policy recommendations derived in Piketty (2014). I discuss these insights below in the section on policy relevance (Section 8.4).

8.2 Models of household heterogeneity

This thesis advances three types of heterogeneous household models. I analyze models with household heterogeneity in earning abilities, a combined concept of heterogeneity in saving behavior, income sources and time preferences rates, and heterogeneity in tastes for bequests. These models have rarely or never been used in the context of comparing policy designs for the regulation of the use and provision of common goods. In this section I explain why each type of heterogeneity is relevant for the in-

[3] If the tax proceeds are invested in productive public capital there is a significant positive effect on growth.

dividual problem and in which aspects the concept goes beyond previous work.

Five of the six main chapters of this thesis, are based on economic models with heterogeneous households. Since the leading topic of Part I are short-term distributional effects of climate policy, the main source of heterogeneity is in earnings ability. Part II is concerned with the rather long-term distributional impacts of infrastructure investment and different types of wealth-based taxes on the wealth distribution. In the second part I hence concentrate on differences in the housholds' saving and bequest behavior.

For modeling the heterogeneity in earnings ability used in Part I, I use a discrete Mirrleesian-type model that generates inequality in income (Mirrlees, 1971). Such models are also used in the context of environmental policy for assessing the optimal tax rules in the presence of an (environmental) externality (see, for instance, Cremer et al., 1998; Jacobs and De Mooij, 2015). I believe that the analyses in Chapters 2 and 3 are the first studies to use such a model structure to analyze the distributional effects of different designs of carbon tax reforms.[4] The work from Chapters 2 and 3 further complements preceding work in this field for two reasons: First, I focus on policy relevant assumptions such as households having to consume a subsistence level of carbon-intensive goods, a government that is constrained to linear carbon taxes and non-linear income taxes and stricter climate policy as a reaction to a greening of preferences for the environment. Second, the numerical solution of the model in Chapter 3 allows for a quantification of the results: Optimal tax rates can be determined before and after a carbon tax reform. This makes the abstract changes in the tax rules, determined by earlier literature, more tangible – and thus more useful for policy advice.

The topics treated in Part II, infrastructure investment and reducing inequality in wealth, require modeling the mechanisms which determine wealth inequality in more detail. The concept of heterogeneity developed in Chapters 5 and 6 is based on the empirical observations that rich households save a higher share of their income than lower income households, that a higher share of their income is from capital, and that they invest more patiently (i.e. they have a lower time preference rate). To the best of my knowledge, Chapters 5 and 6 are the first studies to use this type of heterogeneity in a neoclassical framework in the context of government financing of a public capital stock. Our model is based on Michl and Foley (2004) and Michl (2009), who, by contrast, close their model with a non-marginalist production function. For a classical study of public investment in a two-class model see Tavani and Zamparelli (2015).

As a consequence of these heterogeneity assumptions, some of the results I obtain on the distributional effects of public investment differ from earlier studies on the topic. Another beneficial consequence of this type of model is that most results are very robust with respect to crucial assumptions such as the role public capital plays in utility and production as well as the assumption of

[4]Note that Kaplow (2012) also studies carbon tax reforms in such a model. However, he analyzes optimal carbon tax reforms under the constraint that inequality has to remain at the same level.

constant or decreasing returns to accumulable factors. Further, my results do not rely on the assumption of constant time preference rates across households.

The heterogeneity concept employed in Chapter 7 differs from the concept used in Chapters 5 and 6: In Chapter 7 wealth is disaggregated into land and physical capital. Furthermore, assuming heterogeneity in preferences for bequests allows for more than only two polar cases of saving behavior. The model accounts for the empirical observation that around half of all wealth accumulation can be attributed to intergenerational transfers (Gale and Scholz, 1994) and that bequests are hence an important determinant of wealth inequality (Cagetti and De Nardi, 2008; Kopczuk, 2013). I believe that the study in Chapter 7 is the first study that analyzes output-neutral tax reforms for inequality reduction in a model with heterogeneous preferences for bequests.[5]

In sum, this thesis advances several types of heterogeneous household models, which have only rarely been used before for the assessment of environmental and infrastructure policy designs. However, alternative versions of these models have been used in different contexts before, for example for determining optimal tax rules in the presence of an externality (Jacobs and De Mooij, 2015), in a classical economics context (Michl, 2009; Tavani and Zamparelli, 2015), or for the assessment of socially optimal bequest taxes (Piketty and Saez, 2013; Farhi and Werning, 2013).

8.3 Extensions

This section discusses the limitations and outlines possible extensions of the current work.

Part I: Other intragenerational distributional impacts of climate policy

In Part I, I only consider the aspect of the intragenerational effects of climate policy, which I consider most important empirically. However, there are other intragenerational distributional effects which can also be relevant (Fullerton, 2011): (1) since a higher share of low-skill workers is employed in capital-intensive industries, climate policy might drive them out of work (see, for instance, Babiker and Eckaus, 2007; Fullerton, 2011; Schwerhoff and Franks, 2016). (2) if abatement technologies are capital-intensive, demand for capital could rise, which would depress wages. (3) if a cap and trade scheme were adopted and pollution permits would be grandfathered to firms, scarcity rents would be created, which would benefit the high income firm owners (Parry, 2004). (4) High income households could benefit more from avoided damages if low income households are assumed to attach a lower value to environmental quality. (5) Avoided damages to capital would increase the present value of capital. This would disproportionally benefit households with larger capital holdings.

[5] There are, however, studies which determine the socially optimal level of bequest taxation in related models which do not distinguish between the fixed factor land and reproducible physical capital. See, for instance, Piketty and Saez (2013) and Farhi and Werning (2013).

I refrain from modeling these additional effects for two reasons: First, in the short term, the effect considered in Chapters 2 and 3 is likely to be the empirically most relevant effect. Second, the argument that, due to carbon-intensive subsistence levels of consumption, carbon pricing has a regressive effect is one of the main arguments used for delaying and watering down climate action – by focusing only on this effect, Chapters 2 and 3 demonstrate that the existence of carbon-intensive subsistence levels does not impede strict climate policy (if the tax proceeds are recycled lump-sum).

Part I: The intertemporal component

Chapter 4.3.6 discusses the intergenerational distributional effects of climate policy: Climate policy can also be seen as a problem of distribution between current and future generations, since future generations reap the benefits of climate policies, which are paid for by current generations. It is concluded in Chapter 4.3.6 that Pareto-improving climate policy is feasible (that is, each generation is equally well or better off, with one generation being strictly better off), if transfers between generations are possible. This issue is abstracted from in the model studies in Chapters 2 and 3.

The only study I know of, which treats intra- and intergenerational distributional issues of climate policy in a joint framework is Jacobs and Van der Ploeg (2010). Their conclusions hint at a potential trade-off between intra- and intergenerational equity. I argue that this is not necessarily the case: The intergenerational transfers necessary for generating an intergenerational Pareto-improvement would not interfere with a lump-sum redistribution of carbon tax revenue. There hence would be no reason for a trade-off. It would be worthwhile to include an intertemporal component into the models from Chapters 2 and 3 to analyze this claim in a theoretical framework.

Furthermore, the long-term goal of carbon pricing is to induce a change in the production structure of the economy from carbon-intensive to carbon-free (or at least less carbon-intensive) technologies. Such a structural change would lead to a decarbonization of the economy. As a consequence, one of the main assumptions of Chapters 2 and 3, the existence of a subsistence level of carbon-intensive consumption, would become less relevant as decarbonization progresses. Accounting for structural change in these models would lead to important insights on the trajectories of growth and inequality over the course of the decarbonization. The model used in Chapter 3 would be suited for extending it to include an intertemporal optimization.[6]

Part II: Modeling pollution

Investment in a public capital stock, as in Part II, can also be interpreted as investment in climate change mitigation. The studies hence demonstrate how revenue for climate action can be raised while minimizing the distributional impacts, if the government chooses not to price carbon emissions directly.

[6]The so-called "New Dynamic Public Finance" literature is concerned with extending the static Mirrleesian models to intertemporal settings. For an overview see Golosov et al. (2007).

Nevertheless, introducing an environmental component to these models could yield several additional insights. In the following I outline five conceivable extensions:

First, Heijdra et al. (2006) model environmental pollution as a by-product of physical capital in production. It would be worthwhile to adopt a similar approach in the models from Chapters 5 and 6. In such a model, a carbon tax might have a progressive long-term effect, since households which own proportionally more capital are hit harder by a carbon tax under this assumption.

Second, with an environmental externality explicitly modeled, the equity and efficiency effects of financing public investment through carbon taxes can be analyzed. Taxing carbon should not distort the economy – investment in a public capital stock could hence be enhanced, which could lead to both, enhanced equity and efficiency.

Third, distributional issues related to carbon lock-ins could be analyzed in more detail by distinguishing between clean and polluting capital stocks. A carbon lock-in, which is a state in which carbon-intensive technologies dominate the economy (even though they are inferior to low-carbon technologies in the long run), is a topic of major importance when it comes to the formation of clean and polluting capital stocks. Such a lock-in into inferior, more carbon-intensive technologies is a major obstacle for the transition towards a greener economy (Unruh, 2000). Mattauch et al. (2015) demonstrate that the optimal policy for avoiding a carbon lock-in is a combination of carbon taxes and a learning subsidy for green technologies. They show that, in a second-best setting, in which such subsidies are unavailable to the government, welfare losses are still minor if the carbon tax is set slightly higher.

Such a lock-in is persistent due to the low depreciation rate of both private and public capital. Even though I refrain from distinguishing between low and high carbon public investment in Part II, the results indicate how public investment should be financed to minimize adverse distributional effects.

Fourth, according to Siegmeier (2016), every climate policy goal can be reached either by a carbon tax or by adjusting the composition of public spending, in a framework with clean and polluting public capital stocks and consumption goods. Chapters 5 and 6 suggest that increasing public spending influences economic inequality, both, through the level of public capital, and the effect of the increased taxes. It would hence be worthwhile to not only distinguish between clean and polluting capital stocks but also to introduce such a distinction concerning consumption goods to analyze the distributional effects of different policy pathways associated with a climate goal.

Fifth, distinguishing between clean and polluting capital would lead to another interesting distributional effect, due to the different elasticities between labor and clean and polluting capital.

Part II: Social optimality

Extending the model from Chapters 5 and 6 to determine socially optimal policies and levels of public investment would require implementing a social welfare function. This model features both an overlapping generations (OLG) agent and an infitinitely-lived (IL) agent. Concepts of social welfare functions in models populated only by IL agents and only by OLG agents already exist in the literature (see e.g. Calvo and Obstfeld, 1988 and Cass, 1965). However, I do not know of a concept which incorporates both types of agents. Developing such a social welfare function would yield interesting insights, but it would also require to make further normative assumptions, for example with regard to how the different agents' utilities are discounted by the social planner.

Also the analysis from Chapter 7 could be extended by implementing a social welfare function (using the concept developed by Calvo and Obstfeld, 1988). Additional insights could be derived from the knowledge of the socially optimal bequest tax rate and from optimal bequest taxation in the presence of an externality. To my knowledge there is no work yet on the optimal taxation of bequests in the presence of an externality.

Introducing social optimality in the models developed in Part II would hence yield many new insights but would go beyond the scope of all of these studies.

8.4 Policy relevance

This section discusses the implications of the present thesis for the design of climate policy and policies for infrastructure provision. Furthermore, the main research questions put forward in the introductory chapter will be answered.

8.4.1 Implications for climate policy

The results from Part I suggest that an efficient carbon pricing policy should not be abandoned for distributional reasons. A price should be put on carbon which is determined independently of the distributional impacts of that price, since the regressive effect of carbon pricing can always be neutralized by recycling the tax revenue through monthly (or yearly) cash transfers of equal size to all households. Such a tax reform would not only offset the regressive effects of carbon taxes, it even has the potential to reduce inequality. It furthermore is revenue-neutral since all tax revenue is returned to the households.

Chapter 3 suggests using the revenue for an optimal (progressive) reform of the income tax system. This way of recycling the revenue would compensate the regressive effects of carbon taxes but it would also enhance the efficiency compared to lump-sum recycling. Even though in the model this method might seem superior to revenue recycling through cash transfers, such a reform would likely be too complicated to implement in a real economy. An additional advantage of recycling the revenue through uniform lump-sum transfers is its transparency and visibility: Every transfer received by the households is a reminder that the carbon tax reform is in fact budget-neutral and that poor households not only benefit from avoided global warming but also through the transfers.[7] In sum, this would increase public support for such a carbon tax reform.[8]

It has been argued in the literature that, by recycling carbon tax revenue through rebates in distortionary taxes, two goals might be reached at the same time: a reduction in carbon emissions and a less distorted tax system (this effect has been called the "double dividend", see the reviews in Bovenberg, 1999; Goulder, 1995). The existence and the extent of this effect have been heavily debated in the literature but are not the topic of this thesis.[9] However, this thesis makes two contributions regarding the distributional effects of the "double dividend", and its assessment in an optimal taxation framework: First, if the carbon tax-financed cut in the income tax system is uniform, a "double dividend"-type tax reform might be regressive. Only if the tax revenue is used for a progressive reform of the income tax system, a "double dividend" might be obtained without increasing inequality. Second, in an optimal taxation model with heterogeneous households (as in Chapter 3) the concept of a double dividend is of limited interest, since an optimal tax reform requires adjustments in both the income and the lump-sum taxes. Limiting the government to one recycling mechanism, as is done in most articles in the double dividend literature, inevitably reduces welfare in such a framework.

A policy which recycles carbon tax revenue via uniform cash transfers is not too far from reality: The Citizens' Climate Lobby are proposing a similar scheme already since 2007 on the grounds of revenue neutrality, efficiency, public support and distributional fairness. One of its most famous proponents, James Hansen, explains this so-called "fee and dividend" proposal in more detail in a recent publication. According to Hansen (2015): "Citizens using less than average fossil fuels (more than 60% of the public with current distribution of energy use) will therefore receive more in their monthly dividend than they pay in increased prices." However, Hansen does not mention the subsistence level of carbon-intensive goods, which is responsible for the regressive impact of the carbon tax.

Furthermore, a similar mechanism is in place in Switzerland, where around one third of the carbon tax revenue is spent for energy-efficient renovations of buildings while the remainder is returned to the public: This is done partially in the form of uniform transfers to all households and partially to the business community (Swiss Federal Office for the Environment, 2016).[10]

[7] Congdon et al. (2009), in an article on behavioral economics and tax policy, argue that the framing of tax cuts (either as a bonus or as a rebate) can affect how these tax cuts are perceived. Their argument builds on experiments by Epley et al. (2006) who demonstrate that tax cuts perceived as bonuses are more likely to be spent than tax cuts perceived as rebates.

[8] For instance, Kallbekken and Aasen (2010) and Kallbekken et al. (2011) use lab experiments to demonstrate that public support for Pigouvian taxation is much higher, if the revenues are earmarked to be spent for a specific purpose. Further evidence comes from the transportation literature: Eriksson et al. (2006) and Fujii et al. (2004) find that perceived fairness of a policy such as road pricing or fuel taxes is a crucial determinant of the support for this policy.

[9] In the general equilibrium there are price effects ("tax-interaction effects") which reduce or even offset the beneficial effect of reducing distorting taxes (Bovenberg and De Mooij, 1994).

[10] In 2015 in Switzerland a ton of carbon is priced at 84 Swiss Franks (SFR), around 77 EUR at the exchange rate from the 17.01.2016, which then corresponds to a yearly transfer of 62 SFR (roughly 57 EUR). Note that fuels used for transport purposes such as gasoline and diesel are excluded from the tax. Firms can also solicit a tax exempt but in turn have to commit to certain mitigation goals.

One might wonder if the results from Part I might also be applicable to other taxes which put a disproportional burden on the poor, such as taxes that address an externality associated with the consumption of a certain good. These taxes are often called “sin taxes” in the literature. They aim at internalizing the adverse health effects of the consumption of goods such as tobacco, alcohol, fatty foods and sugary drinks. These “sin taxes” are often considered regressive (at least in the short run) for the same reason as a carbon price: Poor households spend a relatively higher share of their income on these items than rich households (see e.g. Lyon and Schwab, 1995). However, there are two crucial differences to carbon taxes: First, there is no subsistence level of tobacco, alcohol and the likes. Second, rich households do not always spend more money on these goods (which is the case for carbon-intensive goods). The results from Chapters 2 and 3 can hence only be applied to goods on which rich households spend more money than poor households (in absolute terms) and on which poor households spend a larger share of their income. One might speculate that such goods could include alcohol and tobacco, but not fatty foods and sugary drinks.

Finally, the results from Chapter 4 indicate that when climate policy is designed taking interactions with other public policies into account, these interactions have a large potential for reducing the overall cost of climate policy. Some of these effects might provide an incentive to introduce a moderate carbon price even if the government has no incentive to protect the environment. Such a moderate carbon pricing could prevent a carbon lock-in (see p. 218) and keep the door open for future, more ambitious climate policy.

8.4.2 Implications for infrastructure policy

So how should infrastructure policy be designed? The answer to this question also depends on the preferences a society has for equity and efficiency: Chapters 5 and 6 suggest that the effect on the spending side, that is the investment in infrastructure itself, is inequality-reducing. The distributional effect on the revenue-raising side, however, depends on the financing mechanism. In sum, it can be concluded that there is a trade-off between very efficient (but distribution-neutral) consumption tax financing and less efficient (but very progressive) capital tax financing of public investment. Which financing option is used depends on the preferences of the government regarding inequality and growth. Nevertheless, both options lead to Pareto improvements and would hence be preferable to inaction.

An important lesson from Chapter 7 is that some financing options, such as land rent taxation are no-lose options, since they increase both equity and efficiency at the same time. This confirms earlier literature on the topic, see, for instance, Arnott and Stiglitz (1979); Dwyer (2014); George (1879/2006) and Mattauch et al. (2013). This finding hints at the fact that there might be other economic rents that could be taxed to increase public investment without distorting the economy: Siegmeier et al. (2015), for instance, analyze the potential of climate policy to skim off fossil resource rents – they find that climate policy does not only raise additional revenue, it also induces a portfolio effect similar to the effect found in Chapter 7.

Piketty (2014) in his highly influential book “Capital in the twenty-first century” proposes capital tax-financed public investment to reduce wealth inequality. In the book, however, it is not distinguished between land, life-cycle savings and bequest savings. Chapter 7 demonstrates that this distinction is crucial and that, as a consequence, Piketty’s policy recommendation would need some adjustment: A shift from a tax on aggregated wealth towards bequests and land rents would significantly enhance the progressivity and the efficiency of such a policy.

Combining these results with the findings from Part I would suggest a combined policy, in which a part of the carbon tax revenue would be spent on increasing public investment and another part would be used to offset the regressive effects of carbon pricing.

8.4.3 Implications for combating inequality

An egalitarian distribution is, by some authors, interpreted as a public good in the sense that it is non-rivalrous and non-excludable (Rao, 1999; Stanton, 2012; Thurow, 1971). It needs constant investment in order not to deteriorate: Boehm (1999) argues that democratic processes emerged historically as a means for the many weak individuals to control the few strong individuals in a society, to avoid a despotism of the strong. Equity can hence only be sustained by suppressing persistent tendencies towards hierarchy and despotism - that is, by constant investment in this public good. This argument is very much related to the argument made by Piketty (2014), that highly concentrated wealth is the natural state of a capitalist system – only in a short period in the second half of the 20$^{\text{th}}$ century, wealth was less concentrated, as a consequence of highly progressive policies. To reduce the costs of equity-enhancing policies this thesis proposes to design climate and infrastructure polices such that they simultaneously reduce inequality (or such that they are at least distribution-neutral).

Nevertheless, if we assume that inequality-reduction is a goal in itself, which policies would be suitable to reduce inequality without harming growth? Different chapters have different responses to this question: Chapters 2 and 3 would suggest combining a carbon tax with either uniform lump-sum recycling of the revenues, or using the revenues for a progressive reform of the income tax system. The insights derived in Chapters 5 and 6 suggest a policy of capital tax-financed infrastructure. However, if capital is disaggregated as in Chapter 7, a combination of land rent and bequest taxes might work even better, since the revenue-raising alone already reduces inequality significantly without reducing growth. If the tax proceeds are spent on productive public investment there are substantial positive effects on growth.

In sum, this thesis demonstrates that there are several options for reducing inequality when designing policies to regulate the use and the supply of common goods such as the atmosphere and infrastructure.

Even though wealth inequality has increased over the last decades, this should not lead to premature political actions such as an increased taxation of aggregate capital. Chapter 7 demonstrates that taxing aggregate capital indeed reduces inequality, but also implies efficiency losses. More preferable options of inequality-reducing wealth taxation are available which have no or only little negative impact on efficiency such as land rent and bequest taxes.[11] If capital is taxed for the purpose of reducing inequality, the tax proceeds should at least be invested into public capital in order to avoid negative growth effects.

Furthermore, as a consequence of the result of 2015's United Nations Climate Change Conference, climate policy will be of increased importance to policy-makers. It is likely that stricter climate policies will be introduced in the next years, in particular, carbon pricing, since this is the most efficient policy. Policy-makers could seize this opportunity to reduce inequality either by using the tax proceeds for increased public investment, for uniform lump-sum transfers, or for a combination of the two policies.

[11] This confirms a notion by Stiglitz (2015b) that economic rents are one of the key determinants of the currently observed increase in the wealth distribution.

References

Arnott, R. J., Stiglitz, J. E., 1979. Aggregate land rents, expenditure on public goods, and optimal city size. Quarterly Journal of Economics 93(4), 471–500.

Babiker, M. H., Eckaus, R. S., 2007. Unemployment effects of climate policy. Environmental Science & Policy 10, 600–609.

Barro, R. J., 1990. Government spending in a simple model of endogenous growth. Journal of Political Economy 98(5), 103–125.

Boehm, C., 1999. Hierarchy in the Forest. The Evolution of Egalitarian Behavior.

Bovenberg, A. L., 1999. Green tax reforms and the double dividend: an updated reader's guide. International Tax and Public Finance 6(3), 421–443.

Bovenberg, A. L., De Mooij, R. A., 1994. Environmental levies and distortionary taxation. The American Economic Review 84(4), 1085–1089.

Cagetti, M., De Nardi, M., 2008. Wealth inequality: Data and models. Macroeconomic Dynamics 12(S2), 285–313.

Calvo, G. A., Obstfeld, M., 1988. Optimal time-consistent fiscal policy with finite lifetimes. Econometrica 56(2), 411–432.

Cass, D., 1965. Optimum growth in an aggregative model of capital accumulation. The Review of Economic Studies 32(3), 233–240.

Combet, E., Ghersi, F., Hourcade, J.-C., Théry, D., 2010. Carbon Tax and Equity The importance of Policy Design. In: Dias Soares, C., Milne, J., Ashiabor, H., Deketelaere, K. (Eds.), Critical Issues in Environmental Taxation vol. VIII, pp. 277–295.

Congdon, W. J., Kling, J. R., Mullainathan, S., 2009. Behavioral Economics and Tax Policy. National Tax Journal 62(3), 375–386.

Cremer, H., Gahvari, F., Ladoux, N., 1998. Externalities and optimal taxation. Journal of Public Economics 70(3), 343–364.

Dwyer, T., 2014. Taxation: The lost history. American Journal of Economics and Sociology 73(4), 664–988.

Ekins, P., 1999. European environmental taxes and charges: recent experience, issues and trends. Ecological Economics 31(1), 39–62.

Epley, N., Mak, D., Idson, L. C., 2006. Bonus of rebate?: the impact of income framing on spending and saving. Journal of Behavioral Decision Making 19(June), 213–227.

Eriksson, L., Garvill, J., Nordlund, A. M., 2006. Acceptability of travel demand management measures: The importance of problem awareness, personal norm, freedom, and fairness. Journal of Environmental Psychology 26, 15–26.

Farhi, E., Werning, I., 2013. Estate taxation with altruism heterogeneity. American Economic Review 103(3), 489–495.

Fujii, S., Gärling, T., Jakobsson, C., Jou, R.-C., 2004. A cross-country study of fairness and infringement on freedom as determinants of car owners' acceptance of road pricing. Transportation 31, 285–295.

Fullerton, D., 2011. Six distributional effects of environmental policy. Risk analysis 31(6), 923–9.

Gale, W. G., Scholz, J. K., 1994. Intergenerational Transfers and the Accumulation of Wealth. The Journal of Economic Perspectives 8(4), 145–160.

George, H., 1879/2006. Progress and Poverty. An inquiry into the cause of industrial depressions and of increase of want with increase of wealth. The Remedy. Elibron Classics, reprint of the 1894 edition.

Golosov, M., Tsyvinski, A., Werning, I., 2007. New dynamic public finance: a user's guide. In: Acemoglu, D., Rogoff, K., Woodford, M. (Eds.), NBER Macroeconomics Annual 2006, volume 21, pp. 317–388, The MIT Press.

Goulder, L. H., 1995. Environmental taxation and the double dividend: a reader's guide. International Tax and Public Finance 2(2), 157–183.

Hansen, J. E., 2015. Environment and Development Challenges: The Imperative of a Carbon Fee and Dividend. In: Bernard, L., Semmler, W. (Eds.), The Oxford Handbook of the Macroeconomics of Global Warming.

Heijdra, B. J., Kooiman, J. P., Ligthart, J. E., 2006. Environmental quality, the macroeconomy, and intergenerational distribution. Resource and Energy Economics 28, 74–104.

Jacobs, B., De Mooij, R., 2015. Pigou meets Mirrlees: on the irrelevance of tax distortions for the second-best Pigouvian tax. Journal of Environmental Economics and Management 71, 90–108.

Jacobs, B., Van der Ploeg, F., 2010. Precautionary climate change policies and optimal redistribution. OxCarre Research Paper 49.

Kallbekken, S., Aasen, M., 2010. The demand for earmarking: Results from a focus group study. Ecological Economics 69, 2183–2190.

Kallbekken, S., Kroll, S., Cherry, T. L., 2011. Do you not like Pigou, or do you not understand him? Tax aversion and revenue recycling in the lab. Journal of Environmental Economics and Management 62(1), 53–64.

Kaplow, L., 2012. Optimal control of externalities in the presence of income taxation. International Economic Review 53(2), 487–509.

Kopczuk, W., 2013. Taxation of Intergenerational Transfers and Wealth. In: Auerbach, A. J., Chetty, R., Feldstein, M., Saez, E. (Eds.), Handbook of Public Economics, volume 5, Newnes.

Lyon, A. B., Schwab, R. M., 1995. Consumption Taxes in a Life-Cycle Framework: Are Sin Taxes Regressive? Review of Economics and Statistics 77(3), 389–406.

Mattauch, L., Creutzig, F., Edenhofer, O., 2015. Avoiding Carbon Lock-In: Policy Options for Advancing Structural Change. Economic Modelling 50, 49–63.

Mattauch, L., Siegmeier, J., Edenhofer, O., Creutzig, F., 2013. Financing public capital through land rent taxation: A macroeconomic Henry George Theorem. CESifo Working Paper 4280, 1–20.

Michl, T. R., 2009. Capitalists, workers, and fiscal policy: a classical model of growth and distribution. Harvard University Press, Cambridge, MA.

Michl, T. R., Foley, D. K., 2004. Social security in a classical growth model. Cambridge Journal of Economics 28(1), 1–20.

Mirrlees, J., 1971. An Exploration in the Theory of Optimum Income Taxation. The Review of Economic Studies 38(2), 175–208.

Parry, I. W. H., 2004. Are emissions permits regressive? Journal of Environmental Economics and Management 47(2), 364–387.

Piketty, T., 2014. Capital in the Twenty-first Century. Harvard University Press.

Piketty, T., Saez, E., 2013. A Theory of Optimal Inheritance Taxation. Econometrica 81(5), 1851–1886.

Piketty, T., Zucman, G., 2014. Capital is back: Wealth-Income Rations in Rich Countries 1700-2010. Quarterly Journal of Economics 129(3), 1255–1310.

Rao, J. M., 1999. Equity in a global public goods framework. In: Kaul, I., Grunberg, I., Stern, M. A. (Eds.), Global Public Goods, pp. 68–87, Oxford University Press.

Schwerhoff, G., Franks, M., 2016. Optimal Environmental Taxation with Capital Mobility. Unpublished Working Paper .

Siegmeier, J., 2016. Keeping Pigou on tracks: second-best combinations of carbon pricing and infrastructure provision. MCC Working Paper 2/2016, 1–32.

Siegmeier, J., Mattauch, L., Edenhofer, O., 2015. Climate Policy Enhances Efficiency: A Macroeconomic Portfolio Effect. CESifo Working Paper 5161.

Stanton, E. A., 2012. The tragedy of maldistribution: Climate, sustainability, and equity. Sustainability 4, 394–411.

Stiglitz, J. E., 2015a. New Theoretical Perspectives on the Distribution of Income and Wealth among Individuals: Part I. The Wealth Residual. NBER Working Paper Series May(21189).

Stiglitz, J. E., 2015b. The Origins of Inequality, and Policies to Contain It. National Tax Journal 68(2), 425–448.

Swiss Federal Office for the Environment, 2016. Co2 levy. `http://www.bafu.admin.ch/klima/13877/14510/14511/index.html?lang=en`, retrieved 16-01-17.

Tavani, D., Zamparelli, L., 2015. Public capital, redistribution and growth in a two-class economy. Metroeconomica, online first. DOI: 10.1111/meca.12105 .

Thurow, L. C., 1971. The Income Distribution as a Pure Public Good. The Quarterly Journal of Economics 85(2), 327–336.

Unruh, G. C., 2000. Understanding carbon lock-in. Energy Policy 28(March), 817–830.

List of publications

Chapters 2-7 of this cumulative dissertation are based on individual research articles, which are published in, submitted to, or in preparation for submission to the journals listed below. These articles are a joint effort with several colleagues. The individual contributions are described in detail in the statement of contribution on page 229.

Chapter 2 is based on Klenert, D. and Mattauch, L., 2016. How to make a carbon tax reform progressive: The role of subsistence consumption. *Economics Letters* 138: 100-103, (http://dx.doi.org/10.1016/j.econlet.2015.11.019). A previous version is available as an MPRA Working Paper: Klenert, D., and Mattauch, L. 2015. How to make a carbon tax reform progressive: The role of subsistence consumption. MPRA Working Paper, 65919.

Chapter 3 is based on Klenert, D., Schwerhoff, G., Edenhofer, O., and Mattauch, L., 2016. Environmental Taxation, Inequality and Engel's Law: The Double Dividend of Redistribution. *Environmental and Resource Economics*. The final publication is available at Springer via http://dx.doi.org/10.1007/s10640-016-0070-y.

Chapter 4 is based on Siegmeier, J., Mattauch, L., Franks, M., Klenert, D., Schultes, A., and Edenhofer, O., 2016. The fiscal benefits of climate policy: an overview. In preparation for submission to *CESifo Economic Studies*. A previous version is available as a FEEM Working Paper: Siegmeier, J., Mattauch, L., Franks, M., Klenert, D., Schultes, A., Edenhofer, O., 2015. A Public Finance Perspective on Climate Policy: Six Interactions That May Enhance Welfare. FEEM Nota di lavoro, 31.2015.

Chapter 5 is based on Mattauch, L., Edenhofer, O., Klenert, D., and Bénard, S., 2016. Distributional Effects of Public Investment when Wealth and Classes are Back. *Metroeconomica*, 67(3), 603-629, (http://dx.doi.org/10.1111/meca.12117). A previous version is available as a CESifo Working Paper: Mattauch, L., Edenhofer, O., Klenert, D., Bénard, S., 2014. Public Investment When Capital is Back - Distributional Effects of Heterogeneous Saving Behavior. CESifo Working Paper No. 4714.

Chapter 6 is based on Klenert, D., Mattauch, L., Edenhofer, O. and Lessmann, K., 2016. Infrastructure and Inequality: Insights from Incorporating Key Economic Facts about Household Heterogeneity. *Macroeconomic Dynamics*. First view (http://dx.doi.org/10.1017/S1365100516000432). A preliminary version of the article has been published as a CESifo working paper: Klenert, D., Mattauch, L., Edenhofer, O., & Lessmann, K., 2014. Infrastructure and Inequality: Insights from Incorporating Key Economic Facts about Household Heterogeneity. CESifo Working Paper, 4972.

Chapter 7 is based on Franks, M., Klenert, D., Schultes, A. Lessmann, K. and Edenhofer, O., 2016. Is capital back? The role of land ownership and saving behavior. In preparation for submission to *FinanzArchiv/Public Finance Analysis*.

Statement of contribution

Chapter 2: The author of this thesis developed the model, based on preliminary calculations by Linus Mattauch, who suggested the basic research idea. The framing of the research was a joint effort by both authors. The author of this thesis proved the propositions, in collaboration with Linus Mattauch. The author conducted the numerical simulations which are contained in the supplementary material. The author wrote the article, with input from Linus Mattauch.

Chapter 3: The author of this thesis developed the research question with input from Gregor Schwerhoff and Ottmar Edenhofer. The author extended an earlier modeling framework by himself and Linus Mattauch with inputs from Gregor Schwerhoff and is solely responsible for implementing the optimization problem in GAMS. All authors contributed to fruitful discussions of the model results and their interpretation. The author wrote the article with inputs from Gregor Schwerhoff and Linus Mattauch.

Chapter 4: Jan Siegmeier and Linus Mattauch designed research, with refinements from all authors. Specifically, Max Franks developed the argument on tax competition and the author of this thesis developed the argument on inequality reduction. Jan Siegmeier wrote the article with major contributions from all authors, specifically to Sections 4.3.1 and 4.3.3 by Max Franks, and to Sections 4.2.2 and 4.3.5 by the author of this thesis.

Chapter 5: Ottmar Edenhofer proposed to study the model developed in this chapter. Sophie Bénard and Linus Mattauch refined the model and derived some preliminary conclusions and numerical results, presented in the Master Thesis of Sophie Bénard ("Distributional Effects of Financing Public Capital in a Two-Class Society", October 2012, TU Berlin). Building on this, Linus Mattauch and the author proved the propositions. The author contributed the simulations. Linus Mattauch wrote the article with input from the author.

Chapter 6: The basic research idea is due to Ottmar Edenhofer. The author developed the model with input from all co-authors. He is solely responsible for implementing the optimization problem in GAMS. The article was written by the author, with input from Linus Mattauch. All authors contributed to fruitful discussions of the model results. Kai Lessmann and Linus Mattauch helped to improve the manuscript.

Chapter 7: The conception of the research question and the method to address it are due to the joint effort of Max Franks, the author of this thesis, and Kai Lessmann, with additional support by Ottmar Edenhofer. All calculations, the model implementation, data analysis and visualization were conducted by Max Franks, with support by the author of this thesis and Anselm Schultes. Interpretation, discussion, and conclusions were done by Max Franks in close collaboration with the author of this thesis, Kai Lessmann, and Anselm Schultes. The text of the chapter was written by Max Franks, all co-authors contributed refinements.

Tools and resources

All chapters of this thesis were written with $\LaTeX\,2_\varepsilon$ using Miktex (Schenk, 2012) und Texniccenter (TeXnicCenter, 2013).

Chapter 2: The numerical optimization problem in the supplementary material (not included in the final version of the chapter) was solved with GAMS version 23.7.3 (Rosenthal, 2014), using the CONOPT 3 solver (Drud, 1994). R version 3.1.2 ("Pumpkin Helmet", Venables et al., 2015) and Microsoft Excel 2010 were used for post-processing of output and designing the figures.

Chapters 3, 5 and 6: The optimization problems were solved with GAMS version 23.7.3 (Rosenthal, 2014), using the CONOPT 3 solver version 3.15A (Drud, 1994). R version 3.1.2 ("Pumpkin Helmet", Venables et al., 2015) and Microsoft Excel 2010 were used for post-processing of output and designing the figures.

Chapter 7: The optimization problems were solved with GAMS version 23.7.3 (Rosenthal, 2014), using the CONOPT3 solver version 3.14S (Drud, 1994). R version 3.0.2 ("Frisbee Sailing", Venables et al., 2015), perl 5 version 18 and GnuPlot version 4.6 (Williams et al., 2014) were used for post-processing of output and designing the figures.

References

Drud, A. S., 1994. CONOPT – A Large-Scale GRG Code. ORSA Journal on Computing 6(2), 207–216.

Rosenthal, R. E., 2014. GAMS – A User's Guide. GAMS Development Corporation, Washington, DC, USA (September).

Schenk, C., 2012. Miktex 2.9 manual (revision 2.9.4533). `http://docs.miktex.org/manual/`, retrieved 2015-01-29.

TeXnicCenter, 2013. `http://texniccenter.org`, retrieved 2015-01-29.

Venables, W., Smith, D., The R Core Team, 2015. An Introduction to R. `https://cran.r-project.org/manuals.html`, Software Manual.

Williams, T., Kelley, C., Campbell, J., Cunningham, R., Denholm, D., Elber, G., Fearick, R., Grammes, C., Hart, L., Hecking, L., Koenig, T., Kotz, D., Kubaitis, E., Lang, R., Lehmann, A., Mai, A., Bastian, M., Merritt, E. a., Mikul, P., Tkacik, T., Woude, J. V. D., Zandt, J. R. V., Woo, A., Zellner, J., 2014. Gnuplot 4.6 An interactive plotting program. `http://sourceforge.net/projects/gnuplot`, Software Manual.

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