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The impact of standards and regulation on innovation in uncertain markets

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ABSTRACT

This study analyses the impact of formal standards and regulation on firms' innovation efficiency, considering different levels of market uncertainty. We argue that formal standards and regulation have different effects, depending on the extent of market uncertainty derived from theoretical considerations about information asymmetry and regulatory capture. Our empirical analysis is based on the German Community Innovation Survey (CIS). The results show that formal standards lead to lower innovation efficiency in markets with low uncertainty, while regulations have the opposite effect. In cases of high market uncertainty, we observe that regulation leads to lower innovation efficiency, while formal standards have the reverse effect. Our results have important implications for the future application of both instruments, showing that their benefits heavily depend on the market environment.

1. Introduction

Innovation has become an integral part of economic policy to promote growth. However, public financial support (e.g. subsidies) for private innovation activities is constrained by limited public budgets. In this context, shaping the existing regulatory framework to support private innovation activities becomes more relevant and attractive (European Commission, 2016).

Regulatory framework is generally composed of regulations enforced by governmental institutions. Industry and other affected stakeholders may complement these governmental regulations by self-regulatory coordination (e.g. OECD, 1997).[1] Their efforts can result in voluntary commitments and standards released by publicly accredited or even administrated standardization bodies. As formal standards and regulations shape the paths of further technological developments (e.g. Swann, 2000; Blind, 2016), it is highly important to understand their influence and functionality in order to increase economic growth and welfare.

The impact of regulatory instruments on innovation has been discussed with great controversy in academic literature on environmental issues (see for example Palmer et al., 1995 versus Porter and van der Linde, 1995). On the one hand, complying with regulations is likely to increase costs or restricts firms' freedom of action (Palmer et al., 1995). On the other hand, well designed regulation may guide or even force firms to invest in innovative activities, implement innovative processes or release innovative products (Porter and van der Linde, 1995). Furthermore, research shows that the characteristics of regulatory instruments and their flexibility towards implementation are crucial for increasing economic welfare (Majumdar and Marcus, 2001). Not surprisingly, empirical research has given no consistent picture in matters of the impact of regulatory instruments on innovation (e.g. Aschhoff and Sofka, 2009; Blind, 2012).

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[1] This article does not discuss specific regulatory instruments available to the government, rather the focus is placed on regulation as a general form of coercive rule setting and on formal standardization as a self-regulatory activity.

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Our paper is related to two important streams of economic literature. The first stream intensively discusses regulation (in any form) strictly as it relates to environmental issues (e.g. Palmer et al., 1995; Porter and van der Linde, 1995; Majumdar and Marcus, 2001; Hysing, 2009). The second stream investigates regulation outside of the environmental field and considers regulation as a possible barrier to innovation (e.g. Baldwin and Lin, 2002; Galia and Legros, 2004; D'Este et al., 2012; Blanchard et al., 2013). D'Este et al. (2012) analyse regulatory requirements as one of the many barriers to innovation, e.g. financial constraints and a lack of human resources, without an explicit focus on the regulatory framework. However, this stream often neglects self-regulatory instruments. Surprisingly, most of the literature do not differentiate between formal standards and governmental regulations, probably because of a lack of data availability (e.g. Galia and Legros, 2004).[2]

However, it is important to decipher between the two as the instruments differ substantially. Formal standards are developed in recognized standardization bodies and they are voluntary and consensus-driven (WTO, 2011).[3] In contrast, regulations are mandatory legal restrictions released and enacted by the government. Most studies have not stressed this distinction sufficiently when discussing their impact on innovation.

By using a unique dataset for Germany that allows us to differentiate between both instruments, our empirical research contributes to the works mentioned above. More precisely, knowing whether regulations or formal standards have hampered firm innovation activities, we analyse their impact on a firm's innovation efficiency in different market environments. In general, efficiency is defined as the ratio between output and input. For a given output firms using less input are more efficient. For the purpose of this study, input is defined as the amount of resources (innovation expenditures) a firm invests in the innovation process and output is defined as the successful introduction of a new product (innovation) into the market. Hence, efficiency is defined as the capability of a firm to minimize innovation inputs given a certain quantity (or type) of innovation outputs.[4]

Our work is based on two main theoretical concepts: regulatory capture and information asymmetry. Regulatory capture defines the process in which stakeholders (e.g. industry) try to influence the regulation-making body in favour of their own interests (Stigler, 1971). We refer to this concept to highlight the motivations and capabilities of certain actors to influence formal standards and regulations in different market conditions. Information asymmetry models describe a situation where two actors have different levels of information (e.g. Akerlof, 1970). In our analysis, we combine both concepts to better understand the impact of regulation and standardization on innovation in different market conditions. This is done to support the argument that at different levels of market uncertainty, regulatory capture and asymmetric information have different effects on the setting of regulations and the development of standards and their impacts on the concerned organizations.

Based on these theoretical considerations, we develop and empirically test whether regulations and standards have divergent impacts on firms' innovation efficiency at different levels of market uncertainty. Our empirical analysis is based on the 2011 German Community Innovation Survey, a reliable and extensive dataset for firm-level innovation studies. For our analysis, we conduct a Heckman model in order to control for the fact that investment in innovation is only observable for firms that actually have decided to invest in innovation. This approach is common in innovation studies (e.g. Kesidou and Demirel, 2012; Catozzella and Vivarelli, 2014). Our results show that in markets with low uncertainty, firms must spend a higher amount of resources in order to be innovative if they experience problems with standards (i.e. standards decrease firms' innovation efficiency), while regulations have the opposite effect (i.e. they enhance firms' innovation efficiency). In the case of markets with high uncertainty, we find opposite effects: firms that experienced problems with regulations had to spend more resources to successfully introduce an innovation to the market while formal standards have the opposite effect.

Our results enhance the academic discussion on the impacts of formal standards and regulation on innovation. We show theoretically as well as empirically that both instruments have diverse effects on innovation in different market conditions. In addition to the contribution to literature, these results are particularly useful for policy makers to stimulate the discussion on how different regulatory instruments should be used to shape the optimal regulatory framework conditions in different market environments.

We proceed as follows: Section 2 outlines the theoretical framework providing the background to our study. Section 3 discusses the methods and data used. Section 4 presents the results about the impact of regulation and formal standards on firms' innovation efficiency, differentiating between markets with different uncertainty. Section 5 discusses the robustness of the results presented in Section 4. Section 6 concludes with the discussion of the results and their application to innovation policy.

2. Theoretical framework

Before discussing the impact of formal standards and regulations, the differences between both instruments have to be outlined in more detail. Formal standards are the result of a consensual negotiation process carried out by firms and other interested stakeholders in a voluntary process within standardization organizations (WTO, 2011). Therefore, standard setting can be seen as a self-regulatory process (Gupta and Lad, 1983), in which only a limited number of companies are actively involved. For example, Wakke et al. (2015) show that less than 5% of the Dutch service companies are active in standardization.

Regulations are developed and enacted by the government to shape the market environment and influence the behaviour of the concerned actors (e.g. Blind, 2012). Correspondingly, regulations stem primarily from a top-down approach, while formal standards are typically the result of a market-driven process (Büthe and Mattli, 2011), or as Gupta and Lad (1983) frame it: "industry self-regulation" vs. "direct governmental regulation", which we also apply in our conceptual model. Regulations and formal standards also differ substantially in terms of their enforcement. The exertion of regulations is mandatory, while the adoption of formal standards is, in most cases, voluntary.

In contrast to the noted differences, there are interdependencies of the two instruments, especially in the course of the "New Approach".[5] Nevertheless, around a third of European standardization activities are developed to directly support the implementation of European policies (CEN-CENELEC, 2013).

[2] A noticeable exception is the working paper of Swann and Lambert (2010) that without considering uncertainty, investigates innovation success looking at the informative and constraining effects of standards and regulation using UK Community Innovation survey data.

[3] Even though formal standardization is a consensual process, it is often strategically exploited by its participating firms. Hence, firms are using the formal standardization process, e.g. to raise a rival's costs (Salop and Scheffman, 1987; Swann, 2000) to form alliances (Rosenkopf et al., 2001) or to generate knowledge spillovers (Blind and Mangelsdorf, 2013).

[4] We are using a relatively simple measure of innovation efficiency, i.e. innovation expenses of successful product innovators. As shown in the robustness checks in section five, our results are not changing when measuring innovation efficiency as the ratio of innovative sales above innovation costs.

[5] For further information, please refer to www.newapproach.org. A similar division of work has been implemented in Germany.

Table 1
Total effects of both instruments on innovation costs.

	Costs of Regulatory Capture on Innovation Costs	Costs of Information Asymmetry on Innovation Costs	Total effects on Innovation Costs
High Market Uncertainty	Standards = Regulation	Standards < Regulation	Standards < Regulation
Low Market Uncertainty	Standards > Regulation	Standards = Regulation	Standards > Regulation

In the case of the German standards, only 19.6% of published German formal standards are directly linked to governmental regulations.[6] This underlines that formal standards and regulations do interact, but to a relatively limited extent in both a theoretical and an empirical context. Nevertheless, we assume that both instruments have different effects depending on their impact on firms' innovation behaviour at different degrees of market uncertainty.[7]

In the following, we apply the theoretical concepts of information asymmetry and regulatory capture to discuss the diverse impacts of both instruments on innovation in the context of different degrees of technical uncertainty.

2.1. Market uncertainty

In the context of innovation, uncertainty results from different sources like competition, consumer behaviour or technological complexity (e.g. Jalonen, 2011; Sainio et al., 2012). The success of innovation depends largely on the simultaneous and successful interplay of supplying new products and services and the buying behaviour of the consumers. Firms operating in a market with high uncertainty may be confronted by a highly heterogeneous technical landscape and the unpredictable consumer behaviour. Different technologies may compete with each other and thus increase uncertainty among producers and consumers (e.g. Dosi, 1982). An example for such markets might be the automotive market for electric cars, where a dominant technical infrastructure is still missing and producers face problems to predict future development of the technology. In this type of market, aside quality and price as decision parameters, consumers are presented with multiple competing technology options. Waiting for the rise of the dominant technology infrastructure, consumers may postpone buying innovative products, especially if they have difficulties in assessing the intrinsic quality of different technologies. The uncertainty of customer behaviour augments the difficulties of producers to predict technological paths. Demand and supply are closely interrelated and both contribute to shape the uncertainty in the markets (e.g. Jalonen, 2011). We argue that regulation and standards have a substantial different impact on innovation efficiency in markets with different degree of uncertainty.[8]

For the econometric analysis, we operationalize the concept of uncertainty developing a synthetic index of uncertainty, in line with the work of Sainio et al. (2012) that combines different dimensions of uncertainty. The uncertainty index is constructed by summing the maximum score of the self-reported perception of uncertainty on the technological context (i.e. technological development is difficult to predict) and on the quality assessment (i.e. clients have difficulties assessing the quality of products in advance). Community Innovation Survey targets firms and does not include information on the users of innovation. For this reason, the index emphasizes technological aspects of the uncertainty and could be labelled as "technological uncertainty".

2.2. Regulatory capture

As stated in previous section, regulatory capture describes a phenomenon where particular interest groups (e.g. industry) try to influence governmental regulations in terms of their own interests (Stigler, 1971). Generally, all types of rule-setting are endangered by regulatory capture (Laffont and Tirole, 1991). While the concept primarily focuses on the influence on state intervention, i.e. governmental institutions, it can also be used to explain why some firms are lobbying in standardization processes (Blind and Mangelsdorf, 2016). In this context, formal standards can be strategically used to raise rivals' costs by creating market entry barriers (Salop and Scheffman, 1987; Swann, 2000). De Vries (2006), for example, shows that Tyco/AMP gained a considerable edge over its close competitor AT&T by influencing international formal standardization.[9] Moreover, even if formal standards are not mandatory, they can influence the technological infrastructure of a particular market (e.g. Swann, 2000; Blind, 2016). Therefore, they can have a significant impact not only on a firm's compliance, but also innovation costs if the firm relies on a particular standard.[10]

Very strict, specific technical specifications of a standard may be one means by which to increase a firm's competitive advantage (Swann, 2000). The purposeful inclusion of intellectual property (IP) is another option. In particular the GSM standard shows how strategic alliance networks and IP, in the form of essential patents, can have a significant impact on the standardization process (Baron et al., 2016) and market structure (Bekkers et al., 2002). Therefore, the ongoing discussion on the strategic implementation of IP into standards (e.g. Rysman and Simcoe, 2008; Berger et al., 2012) points toward another occurrence of regulatory capture within the realms of formal standardization processes.

We postulate that the effects of regulatory capture on formal standardization vary according to the level of market uncertainty. In instances of markets with low uncertainty, firms have a much better chance to influence formal standards to align with their technological preferences, e.g. by pushing up the required quality level of already established products as already argued by Swann (2000) in a static market environment. Under these conditions, firms involved in standard setting have more time to identify and involve interested stakeholders and to find a consensus to set standards in a way to minimize their proprietary compliance and innova-

[6] The data are retrieved from the Perinorm database (https://www.perinorm.com). Up to 2014 out of 38,216 German formal standards only 7,683 were referenced in regulations.

[7] Among all firms that have extended innovation projects because of standards or regulations, only 27% have experienced problems with both regulations and standards highlighting the distinct effects of both instruments.

[8] Possible interactions between regulatory instruments and market uncertainty are not explicitly modelled for the sake of simplicity. We acknowledge that regulatory instruments may shape the market conditions and reduce market uncertainty in the long-run. However, we note that in the short-run policy makers and other economic actors cannot immediately and directly modify the uncertainty in a market.

[9] Prior literature highlights the concept of regulatory capture to primarily refer to regulations and rules imposed by the government. Following Swann, (2000), we expand the breadth of the initial concept of regulatory capture in order to introduce it to rule setting (self-regulation) outside of the governmental sector. As for regulations, firms might try to "capture" standards in order to benefit from their underlying infrastructure as supported by Blind and Mangelsdorf (2016) which explores companies' motives for engaging in standardization.

[10] It is important to mention that we assume that those compliance costs are part of a firm's innovation expenditures.

Table 2
Descriptive statistics of the variables used in the analyis.

Variable	Description	mean	sd.
Variables of interest			
Standards	Standards extended the duration of innovation projects in 2008–2010	0.034	0.18
Regulation	Regulation extended the duration of innovation projects in 2008–2010	0.035	0.18
No uncert.	Index of uncertainty. For each observation, the index takes the maximum score of self-reported difficulty to predict technological development and difficulties of clients to assess quality. (cat.)	0.092	0.29
Low uncert.		0.34	0.47
Medium uncert.		0.44	0.50
High uncert.		0.13	0.34
Dependent variables			
P. innovator	Firms reporting innovation success (product, process) or any innovation activity (ongoing, discontinued, abandoned), i.e. innovation active firms.	0.56	0.50
Inn. costs	Total innovation costs 2010 per employee (ln)	7.58	1.59
Control variables			
Size	Ln. employees in 2010 (c)	3.67	1.65
Group	Part of a group	0.30	0.46
Low Tech	NACE: 10–17, 18 excl. 18.2; 31; 32 excl.32.5	0.12	0.32
M-L Tech	NACE: 18.2; 19; 22–24; 25 excl. 25.4; 30.1; 33	0.16	0.37
M-H Tech	NACE: 20; 25.4; 27–29; 30 excl.30.1 and 30.3; 32.5	0.15	0.36
High Tech	NACE: 21; 26; 30.3	0.070	0.25
Utilities	NACE: 41–43	0.075	0.26
Construction	NACE: 45–47	0.017	0.13
Trade	NACE: 49–53	0.047	0.21
Transport	NACE: 55–56	0.059	0.23
ICT	NACE: 58–63	0.081	0.27
Financial	NACE: 64–66; 68	0.029	0.17
Profess. and RE	Professionals and Real Estates NACE:69–75	0.15	0.36
Support services	NACE:77–82	0.049	0.22
Local	Sales in regional market	0.37	0.48
National	Sales in national market	0.51	0.50
EU	Sales in EU, EFTA or UE candidates	0.061	0.24
International	Sales in other markets	0.061	0.24
0 comp.	No main competitor	0.061	0.24
1–5 comp.	1–5 main competitors	0.38	0.49
6–10 comp.	6–10 main competitors	0.23	0.42
11–15 comp.	11–15 main competitors	0.079	0.27
16–50 comp.	16–50 main competitors	0.092	0.29
50+ comp.	More than 50 main competitors	0.16	0.36
Education	% of employees with university degree (c)	21.9	26.0
No R&D	No in-house R&D in 2008–2010	0.29	0.45
Occasional R&D	Occasionally in-house R&D in 2008–2010	0.51	0.50
Continuous R&D	Continued in-house R&D in 2008–2010	0.19	0.40
Science Coop.	Cooperation with universities, public or private institutes	0.38	0.49
Market Coop.	Cooperation with clients or customers	0.19	0.39
Other firms Coop.	Cooperation with competitors or other enterprises of the same sector	0.28	0.45
Subsidies	Received any public financial support in 2008–2010	0.40	0.49
Observations		4,027	

Variables are dummies, unless otherwise indicated; (cat.) = categorical variable; (c) = continuous variable; innovation costs, R&D and cooperation and subsidies statistics are computed for the 2254 innovation active firms only.

tion costs. Accordingly, firms not involved in setting the standards are apt to face higher compliance and innovation costs, because the standards may be not in line with their preferred production technology.

In contrast to formal standards, regulations are defined by governmental institutions. However, despite the implementation of counteractive measures, such institutions are not immune to regulatory capture. As Stigler (1971, p. 4) points out, political systems "[...] are appropriate instruments for the fulfilment of desires of members of the society". Based on that, one might argue that the costs of regulatory capture to regulation might not significantly differ from the cost of regulatory capture to formal standards. Nevertheless, in case of formal standardization, firms do directly lobby within the standardization processes following their particular interests, while in cases of regulation, lobbying takes place indirectly. Correspondingly, we argue that the effects of regulatory capture are much more significant in instances of formal standardization.

In the case of high market uncertainty, the effects of formal standards and regulation in relation to regulatory capture do not differ substantially from each other. In such market environments, it can be difficult to identify the superior standard (Cabral and Salant, 2014) and subsequently raise competitors' costs by influencing formal standards using the formal standard setting process. Indeed, in more dynamic markets, several technological paths are possible, while market conditions might change often and into unpredictably. When markets are characterized by higher technological uncertainty, path dependency should be less pronounced.

In such markets, setting standards according to personal technological preferences and potentially raising rivals' costs is expected to be much more difficult. This is due to the fact that when the technology is not yet determined, it may be easier to work around a particular standard. Consequently, in highly uncertain markets it is difficult to influence all possible future developments via standards to increase a firm's competitiveness, e.g. by raising rivals' costs.[11]

The same applies for regulation. Even if lobbying is possible, the direction of technological development is unclear. Therefore, the innovation costs caused by regulatory capture associated with regulation and with formal standards are the same in case of high market uncertainty.

In summary, from a regulatory capture point of view, innovation costs associated with formal standards are higher than for regulation at a lower level of market uncertainty, while they should not differ significantly in cases of high market uncertainty. Based on these considerations, we derive our first hypothesis:

H1. In markets with low uncertainty, formal standards reduce firms' innovation efficiency stronger compared to regulation.

2.3. Information asymmetry

Standards setters and legislators have different levels of knowledge about technological frontier. In this section, we propose that this information asymmetry plays an important role in how regulations or formal standards affect firms' innovation process.

We argue that, in most cases, a mismatch exists between the specifications of existing regulations and formal standards on the one hand and the actual opportunities offered by the insight generated at the dynamic technological frontier on the other hand. Our assumptions are based on Keck (1988), who shows that government technology programs are often inefficient in terms of a significant mismatch between actual costs and realized benefits. He calls such programs "white elephants". One of the main assumptions Keck makes – responsible for the existence of such white elephants – is that the government has less information about the economic value of a technology than the market actors (i.e. industry) do. Accordingly, we argue that regulatory authorities and market actors have imperfect information as to how formal standards or regulations should be set in accordance with the actual technological frontier. Nevertheless, market actors should always have comparatively better information than governmental actors because of their more robust knowledge of existing technological opportunities.

Just as for regulatory capture, information asymmetries differ in reference to different levels of market uncertainty. In case of no uncertainty, full information is – in theory – available to all economic players (including regulators) that have access to the same information, no information asymmetries exist. Therefore, formal standards and regulation perfectly support the in the market implemented technologies and should – on average – have no significant negative impact on firms' innovation costs.

When markets are characterized by rapidly changing and heterogeneous technical landscapes, the probability of a technological mismatch increases and then differences in knowledge between regulators and market actors can be more important for innovation. Jalonen (2011, p. 26) comes to the conclusion "[...] that the more unknown the domain (e.g. consequences and technology) of the innovation, the more ambiguous are the regulations and, hence more uncertainty is felt by innovators." This coincides with our argumentation that market uncertainty increases the potential for technological misfit.

Whereas formal standards are the result of a market and industry driven approach, regulations are generated by a top-down approach and eventually enacted by the government. Consequently, in uncertain markets regulators are confronted with a higher level of information asymmetry than market actors engaged in formal standard setting activities being closer both to technologies provided by the supply side and changes on the demand side.[12]

Based on these conditions, we argue that in markets with high uncertainty, formal standards generate lower compliance and consequently innovation costs as they provide a better fit to the existing technological opportunities, while regulations have the opposite effect. As a result, innovation costs required by the implementation of formal standards are lower than costs related to compliance with regulations in instances of higher market uncertainty.

Based on these considerations, we develop our second hypothesis:

H2. In markets with high uncertainty, regulation reduces firms' innovation efficiency stronger compared to standards.

2.4. Total effects of formal standards and regulation

Based on the conceptual considerations outlined above, we compare the total effects of regulation and formal standards on innovation costs in the case of high and low market uncertainty. Table 1 summarizes this comparison (a detailed description of the derivations for the total effects can be found in the Appendix A).

In case of high market uncertainty, regulations impose higher compliance and consequently innovation costs as they suffer from a higher amount of information asymmetry, while the effects of regulatory capture are similar with both instruments. In case of low market uncertainty, standards are linked to a higher compliance and consequently also to innovation expenditures as they are more prone to regulatory capture, while the effects of information asymmetry do not differ between regulations and standards.

3. Data & method

3.1. Data

For our empirical analysis, we use data from the German 2011 Community Innovation Survey (CIS) to analyse the impact of formal standards and regulation on firms' innovation efficiency. The German CIS is carried out by the Centre for European Economic Research (ZEW) on an annual basis and includes manufacturing and service firms with five or more employees. Descriptive statistics including precise economic industry coverage is provided in Table 2 and correlation table is reported in Appendix Table A1 (for exhaustive information on the collection of the data, the questionnaire and descriptive statistics, please refer to Aschhoff et al., 2013). The German 2011 CIS includes questions discussing the impact of regulation and formal standards as impeding factors for a firm's innovation activities, which are key variables for our model. The

[11] We are not suggesting that firms are not competing for imposing their technology. We are modelling regulatory capture that can take place during formal standard setting or rule setting processes. In this model, if a firm succeeds to impose its technology in the market, there is no uncertainty. The situation can be described as a betting game. The probability that a technology, sponsored by a firm during the standardization process, is successful in the market is lower when several technical paths exist. As lobbing for a particular standard is limited (due to both technical and financial reasons), firms can only bet on a very limited number of different standards.

[12] In case of standardization, information asymmetry may exist between standardizers and non-standardizers. Hence, firms active in formal standardization might come up with technical standards neglecting the requirements relevant for non-standardizers. Among standardizers, information asymmetries should barely exist as formal standardization process is characterized by a high degree of openness and unanimity. However, participation in formal standardization is open to all market actors and the drafts of formal standards are accessible for all interested stakeholders. Our point is that even if standardizers may come up with standards that may be not the perfect match for all market actors, on average the standards match better the technological frontier than the regulation.

Table 3
Average marginal effects—Heckmann model.

	First stage (1): Likelihood of being an innovation-active firm		Second stage (2): Innovation costs	
Standard			0.121	(1.28)
Regulation			0.206**	(2.03)
No Uncertainty	Ref.		Ref.	
Low Uncertainty	0.0595**	(2.36)	0.375*	(1.82)
Medium Uncertainty	0.100***	(4.04)	0.679***	(3.36)
High Uncertainty	0.107***	(3.66)	0.709***	(3.01)
Size	0.0684***	(13.41)	0.331***	(8.55)
Group	0.0210	(1.23)	0.232*	(1.81)
Education	0.00297***	(9.01)	0.0255***	(10.36)
Local	Ref.		Ref.	
National	0.129***	(7.50)	1.179***	(8.76)
EU	0.252***	(7.60)	2.271***	(9.89)
International	0.191***	(5.47)	1.877***	(7.58)
No R&D			Ref.	(.)
Discontinuous R&D			0.456***	(7.97)
Continuous R&D			−0.145**	(−2.32)
Subsidies			0.306***	(5.84)
Science Coop.			0.0225	(0.40)
Market Coop.			0.0754	(1.37)
Other firms Coop.			0.233***	(4.48)
0 comp.	Ref.		Ref.	
1–5 comp.	0.185***	(5.62)	1.282***	(5.14)
6–10 comp.	0.170***	(4.97)	1.187***	(4.63)
11–15 comp.	0.114***	(2.92)	0.826***	(2.87)
16–50 comp.	0.137***	(3.69)	0.978***	(3.56)
50+ comp.	0.0759**	(2.13)	0.563**	(2.09)
Observations	4,027		4,027	

t statistics in parentheses.
Notes: Estimations based on the model 5 (Appendix A Table A2) innovation costs of innovators only; non engaged innovators have zero (0) innovation costs; sectors variables are not reported; effects of competition on innovation costs are only indirect.
* $p<0.10$.
** $p<0.05$.
*** $p<0.01$.

usage of the German CIS is appropriate as German firms are – compared to other European firms – very active in formal standardization (ISO, 2011, p. 47).

The original sample of the German 2011 CIS includes 6,851 observations. After removing observations with missing information, we obtain a sample of 4,133 observations which is used for the subsequent analysis.

3.2. Heckman selection model

For our analysis it is important to differentiate between two types of innovation barriers: revealed and deterring barriers as discussed by D'Este et al. (2012). A "revealed barrier" (e.g. formal standards) increases a firm's perception of that particular barrier but does not deter the firm from innovating. This type of barrier may in fact stimulate a positive learning process within firms (e.g. the firms learn to cope with that particular barrier). Contrastingly, a "deterring barrier" describes a barrier which discourages a firm from engaging in the innovation process (D'Este et al., 2012). Our analysis focuses on the revealing effect of standards and regulation because, firms answer to the question whether standards (regulation) "extended the duration of innovation projects" (Appendix A reports the full question).

Innovation costs are observable only for firms engaged in the innovation process. This may generate a potential self-selection bias (Mairesse and Mohnen, 2010; Archibugi et al., 2013). Moreover, an analysis restricted to innovating firms only would have ignored information regarding non-innovating firms. The subsequent results would thereby be difficult to extend to the whole population of firms. For this reason, a Heckman selection model (Heckman, 1979) is used. The Heckman model on German CIS data has been applied before by Rennings and Rammer (2011) to analyse the impact of environmental regulation on firm's innovativeness. Mate-Sanchez-Val and Harris (2014) use a Heckman model in combination with CIS data analysing firms' innovation activities. In line with Archibugi et al. (2013), we restrict our analysis to innovators only in the robustness check section. The Heckman model allows for the prediction of the innovation costs for all firms in the sample based on the observed characteristics. This is relevant because small and service firms without formal R&D department may have difficulties to report correctly innovation figures (OECD, 2005). After estimating the model, we compare the costs to firms introducing product innovation and reporting problems with regulations or standards.

The Heckman model (Heckman, 1979)[13] can be formally described as following:

$$\mathbf{z}_j\gamma + u_{2j} > 0 \quad (1)$$

$$y_j = \mathbf{x}_j\beta + u_{1j} \quad (2)$$

$$u_1 \sim N(0, \sigma) \quad (3)$$

$$u_2 \sim N(0, 1) \quad (4)$$

$$corr(u_1, u_2) = \rho \quad (5)$$

The model contains two stages: the first stage (Eq. (1)) models the decision of a firm to engage in innovation activities, where $\mathbf{z}_j$ represents the firm's features related to the innovation probability. The second stage of the model (Eq. (2)) analyses the total amount of a firm's innovation expenditures. In doing so, variable $\mathbf{y}_j$ depicts the amount of innovation costs as a linear function of the variables of

[13] The formal description is based on the STATA reference journal (STATA Corp., p. 781).

interest ($\mathbf{x}_j$) which can only be observed if a firm decides to engage in innovation activities. The model assumes that the error terms of the formulas (1) and (2) are characterized by a bivariate normal distribution. The correlation of both terms is represented by the correlation coefficient ρ (Eq. (5)). The estimation is performed using full maximum likelihood estimation.

Our final empirical model is formulated as follows[14]:

$$StageI: Propensity\ to\ innovate\,(P.innovator) = \beta_0 + \beta_1 Market\ Uncertainty^{mu} + \beta_2 Size + \beta_3 Group + \beta_4 Education + \beta_5 Market^{ma} + \beta_6 Compet.^{nc} + \varepsilon \quad (6)$$

mu $\in$ {No, low, medium and high market uncertainty}ma $\in$ {Regional, national, European and international market}nc $\in$ {0, 1–5, 6–10, 11–15, 16–50 and 50+ competitors}

$$StageII: Innovation\ Cost = \beta_0 + \beta_1 Z + \beta_2 Regulation + \beta_3 Standards + \beta_4 Inn.exp^{rd} + \beta_5 Subsidies + \beta_6 Corp.^{C} + \phi + \varepsilon \quad (7)$$

Z Describes a vector including variables used in stage I without *Compet.*^{nc}.ϕ Estimated residuals from stage I.rd $\in$ {No R&D, discontinuous R&D and continuous R&D}C $\in$ {Market cooperation, scientific cooperation, cooperation with other firms}

The first stage of the model (Eq. (6)) analyses a firm's decision to engage in innovation activities (P. innovator) which is defined as a binary variable. A firm is characterized as an innovation-active firm if it reports innovation success (i.e. product, process, organizational or marketing innovation) or any innovation activities (i.e. including ongoing, discontinued or abandoned research projects) between 2008 and 2010.

The independent variables in the first stage are: Market uncertainty (Market Uncertainty), firm size (Size), if the firm is part of a group (Group), education of the labour force (Education), market scope (Market) and the number of competitors in a firm's main market (Compet.). Market uncertainty is operationalized as a categorical variable measured on four levels: none, low, medium and high market uncertainty. For each observation, an uncertainty index is constructed taking into account the maximum score of the self-reported situation on the market environment (i.e. technological development is difficult to predict, clients have difficulties assessing the quality of products in advance).[15] Size is measured by the number of employees in logarithm. Education describes the percentage of employees in the firm with a university degree. Market scope depicts the activity of a firm in local, national, European and international markets.

The second stage of the model (Eq. (7)) analyses the total amount of a firm's innovation costs. The independent variable (Inn. cost) is defined as the total amount of innovation costs between 2008 and 2010 per employee in logarithm. Regulation and standards can influence several aspects of innovation costs (personnel, services of third parties, consumables).[16] Therefore, in line with the definition of the Oslo Manual (OECD, 2005) the analysis considers not only in-house R&D, but incorporates also costs in external R&D, acquisition of software and external knowledge that is particularly relevant for the innovation success of small firms and service firms (e.g. Rammer et al., 2009; Mangiarotti and Riillo, 2014).

The vector **Z** includes Market uncertainty (Market Uncertainty), firm size (Size), if the firm is part of a group (Group), education of the labour force (Education), market scope (Market).

Additional to the variables of the first stage, we include the variable of interest that is whether a firm experienced some form of impairment of its innovation projects caused by regulations (Regulation) or formal standards (Standard). The exact wording of the questions discussing the effects of regulation and formal standardization on innovation is reported in the Appendix A (Question Q.1). The number of competitors (Compet.) is excluded for model identification.[17]

Based on the work of previous studies on the German CIS (e.g. Griffith et al., 2006), additional control variables are included in the second stage: a dummy variable measure if the firm has received any public financial support between 2008 and 2010 (Subsidies) and if it cooperates with universities, public or private institutes (Science Coop.), clients or customers (Market Coop.) and competitors or other enterprises of the same sector (Other firms Coop.). In house R&D indicates if a firm conducted no, occasional or continuous in-house R&D in 2008–2010. The descriptive statistics of the variables discussed above are included in Table 2.

Table 4
Wald tests of Differences between Innovation Costs.

Technological uncertainty	$IC_r - IC_s$	Z statistic
None	−0.950***	(0.335)
Low	0.056	(0.209)
Medium	0.009	(0.351)
High	0.822**	(0.351)

Notes: ICr = Innovation costs due to regulation; ICs = Innovation costs due to standards. θ = technological uncertainty; Z statistics in parentheses; Successful Innovators only; Non innovation-active firms have no innovation expenses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

4. Results

In the following section, we present the empirical results of our analysis. Several model specifications (see the Appendix A Table A2) are used to indicate the appropriateness of our final econometric model. We note that the Rho (ρ) is positive and statistically significant, suggesting that the Heckman model is appropriate for our dataset and that unobservable features (e.g. firm culture) positively affect the propensity and the intensity of innovation. The estimates of our final model (see the Appendix A Table A2, model 5) are chosen as they are characterized by the most exhaustive specifications and the lowest log likelihood. As our model includes several interactions and the average marginal effects are easier to interpret (Williams, 2012), for the sake of simplicity, we report and discuss the average marginal effects indicated in Table 3.

The first stage of the model discusses the likelihood that a firm is an innovation active firm. In line with Griffith et al. (2006), the model fits the data satisfactorily, predicting almost 46% of the

[14] The description of the model follows Rennings and Rammer (2011).

[15] This synthetic indicator is constructed using questions of a unique module of MIP questionnaire about the characteristics that describe the competitive situation of the enterprise. The exact wording of the questions for the calculation of market uncertainty is reported in the Appendix (Question Q.2).

[16] Unfortunately, the dataset does not allow us to directly observe the costs related to the compliance with standards or to regulations related to specific standards. However, we rely on the empirical analyses conducted by Jaffe and Palmer (1997), indicating a positive effect of compliance expenditures on R&D expenditures as well as Ford et al. (2014) who note a positive correlation between both indicators.

[17] Our model hinges on the idea that the number of competitors in the market influences the chances of engaging in innovation but does not determinate the absolute innovation expenditures. The number of competitors influence the decision to invest in innovation activities, as innovativeness is a strong condition if a firm is going to survive in a particular market (Aghion et al., 2002). On the other hand, the number of competitors do not necessarily influence innovation expenditures. In an oligopolistic market, for example smartphones (Apple vs. Samsung vs. Huawei), the limited number of competitors does not lead to a decreasing level of innovation expenditures. The same holds true for non-oligopolistic markets, Biotech, for example. Owing to that, the number of competitors should have no systematic impact on the level of innovation expenditures.

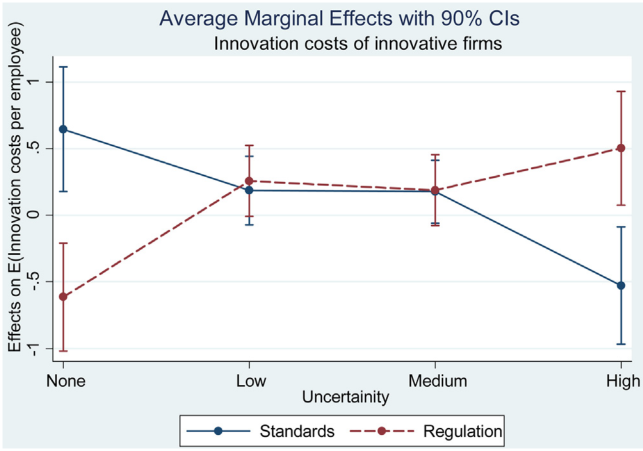

Fig. 1. Average marginal effects of standards and regulation on innovation costs for successful innovators at four levels of market uncertainty.
Notes: Specification (5) Successful Innovators only; Non innovation active firms have zero (0) innovation costs; Controls are: size, group, sector of activity, export activities in terms of main market, formal in-house R&D activity, subsidies, innovation cooperation agreement with science institutions, market players and other firms. The lines are interpolated and are not directly estimated.

observations correctly, as shown in Table 4 in the Appendix A. The cut-off value for correct prediction is the unconditional average of innovation active firms.

When discussing the effects of the control variables, we find that the probability of being an innovation-active firm increases with market uncertainty. In line with previous studies (e.g. Mairesse and Mohnen, 2010), firm size and education of the workforce are also found to increase the probability of a firm being an innovation-active firm. The export activities (i.e. the internationalization of the business) are positively correlated with innovation propensity suggesting a close link between international competition and innovation (Griffith et al., 2006). The propensity of being an innovation-active firm is the highest if a firm is active in the European market. The relationship between the number of competitors and the likelihood of being an innovation-active firm can be described as a reverse U-shape, which is in line with the findings of Aghion et al. (2002).

The second stage of the model analyses firm innovation costs. We find that on average – without distinguishing between different levels of market uncertainty – regulation leads to an increase of innovation costs, while formal standards have no significant effect. As found in the first stage, market uncertainty increases a firm's innovation costs. Firm size, group membership and education of the work force also have positive effects on such costs, although those of the latter are only marginal.

Export activities are positively correlated with innovation costs. We also find that performing discontinued R&D requires more resources, while continuous R&D decreases the innovation costs. This may be because of high R&D set-up costs and the time dependence of R&D. Not surprisingly, subsidies lead to an increase in R&D expenditures. With respect to cooperation, only cooperation with other firms has a significant effect on a firm's innovation costs. Finally, regarding the goodness-of-fit, we note that the residual analyses reported in the Appendix Fig. A1, generally, do not show particularly problematic issues.

After presenting the general results of the Heckman model, we analyse the correlation of formal standards vs. regulations and innovation costs at different levels of market uncertainty. As shown in Fig. 1, regulation and formal standards show different patterns at different levels of uncertainty, which is in line with our hypotheses. The ordinate indicates the level of market uncertainty. The effects of regulation (red line) and formal standards (blue line) on firms' innovation costs (of successful innovators only) at different levels of market uncertainty are shown on the abscissa.

As Fig. 1 indicates, formal standards increase firms' innovation costs more than regulation in markets with low uncertainty, which strongly supports our first hypothesis. Furthermore, Fig. 1 indicates that regulation leads to an increase in firms' innovation costs in markets with high uncertainty, giving strong support to our second hypothesis.

More precisely, in markets with low and medium uncertainty, regulation and standards have a comparable effect. Contingent upon whether a firm reported any innovation activities, firms which experienced obstacles with standards are more likely to report higher innovation costs in markets characterized by low uncertainty, while firms with regulation as obstacle report lower innovation costs. When considering a highly uncertain market, firms that report obstacles due to formal standards report lower innovation costs, while firms experiencing obstacles due to regulation report higher. In markets with low and medium uncertainty, there is no statistically significant difference between the effects of regulation and standards.

In addition to the graphical representation above, our two hypotheses are formally tested (Table 4). We assess the difference between the mean effects of regulation minus the mean effects of the standards by conducting a Wald test. Table 4 indicates that, conditional to a firm having reported any innovation activity, the cost of formal standards for successful innovation is higher compared to regulation in the case of low market uncertainty. In case of high market uncertainty, the cost of regulation on successful innovation is higher compared to the costs induced by formal standards. As shown in Fig. 1, in markets with low and medium uncertainty, the impact of regulation and formal standards on innovation expenditure are substantially the same.

5. Robustness checks

An extensive robustness analysis is conducted to assess the stability of our results. The main pattern displayed in Fig. 1 does not change significantly, as shown in Fig. 2

The literature relating to barriers emphasizes that barriers might hamper the completion of innovative projects only on firms that are actually engaged in innovation activities (Savignac, 2008; D'Este et al., 2012). For this reason, firms that are not interested in innovation (i.e. not investing in innovation) are generally excluded from the analysis. Similarly to Archibugi et al. (2013), we re-estimate the model using only firms that report positive innovation costs (Graph 1 in Fig. 2). Additionally, we test our hypothesis regressing innovation expenditures on the sample of firms with positive innovation costs and product innovation (Graph 2 in Fig. 2). Graph 1 and 2 show that the pattern remains substantially unchanged.

As an additional control, we re-estimated the model considering a different measure of innovation efficiency. More precisely, as shown in Graph 3 of Fig. 2, we use the ratio of innovative sales on innovation costs in natural logarithm as the dependent variable in the second equation, in line with Catozzella and Vivarelli (2014). The main difference is that we take the natural log of the ratio because it is skewed and presents extreme values. As further check, we run the regression dropping the top 5 percentiles and we find similar results. Consistent with our previous results, firms experiencing problems with formal standards, i.e. formal standards were responsible for causing delays to innovation projects, in markets with low uncertainty are characterized by a lower degree of innovation efficiency compared to firms experiencing problems with regulation. The pattern reverses when uncertainty in the market is high. The model estimates for different specifications are available in Table A3 in the Appendix A. Additionally, we regress the ratio

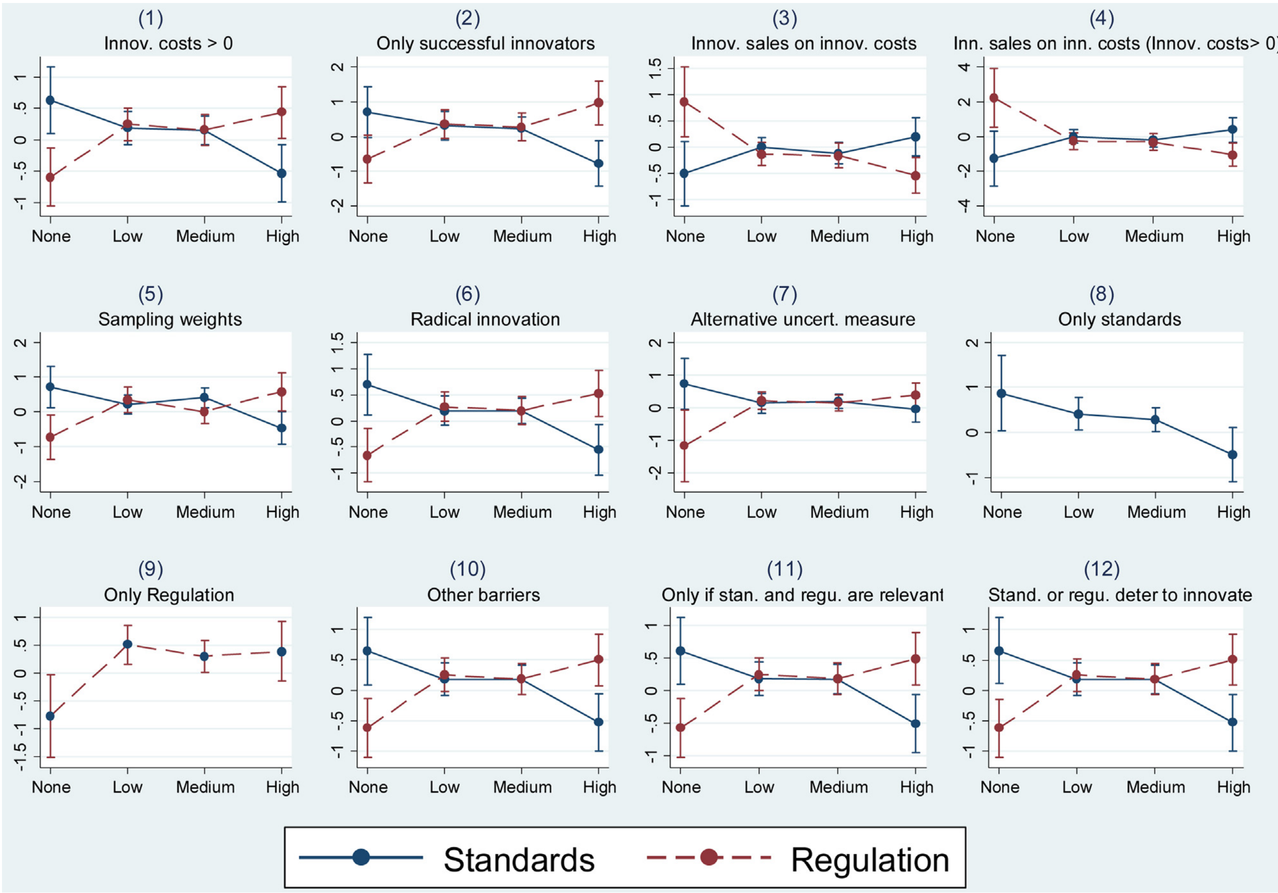

Fig. 2. Robustness checks.

of innovative sales on innovation costs using only the firms with positive innovation expenditures, as suggested by the innovation barrier literature (Savignac, 2008; D'Este et al., 2012). Regulation and standards show a consistent pattern. Model estimates are available in Table A4 in the Appendix A.

The analysis of survey data may require the use of sampling weights to account for the complex survey design (i.e. oversampling of a particular subpopulation) or non-response adjustments as suggested in the methodological literature (e.g. Winship and Radbill, 1994; Lohr, 2010). For example, in their study on the Italian Community Innovation Survey 2002–2004, Evangelista and Vezzani (2010) use weighted data to compute descriptive figures but perform statistical and econometric analyses using un-weighted firm-level data. To evaluate the potential impact of sampling weights on our analysis, the econometric model is re-estimated using survey sampling weights. As reported in Graph 5 in Fig. 2, comparing weighted and unweighted results, the impact of standards and regulation increases in magnitude, but patterns remain markedly unchanged. Graph 6 shows that the pattern is unchanged when considering different definitions of innovation activities (i.e. when radical innovation is measured as the introduction of an innovative product new for the market). As a further robustness check, a different measure of uncertainty is calculated considering the unpredictability of competitor behaviour and of the quality of products/services perceived by the customer. Graph 7 in Fig. 2 shows that the patterns stay substantially unchanged, but standard errors become larger at the high uncertainty level.

As discussed in the introduction, sometimes regulators may explicitly refer to standards. Therefore, suspecting potential multicollinearity between regulation and formal standards, we repeated the econometric analysis using more parsimonious specifications, including one variable of interest at the time. However, the results remain substantially the same.[18] As shown in Graphs 8 and 9 in Fig. 2, when restricting the analysis to firms explicitly reporting that regulation and formal standards are relevant for their innovation activities, the main result of the econometric analysis remains unchanged. Graph 10 shows that results do not change when controlling for potential impacts of all other barriers (e.g. financial constraints). Graph 11 reports results of the model excluding firms for whom standards and regulations are not relevant. In other words, echoing the barrier literature, we include only firms that are reporting that standards and regulations are influencing their innovation process. Results are substantially unchanged. Potentially, formal standards and regulation could deter firms from starting innovation projects. Even when accounting for the potential deterring effect of formal standards and regulation, the pattern remains (Graph 12). Summing up, the patterns discussed in the previous section appears to be substantially unaffected by several robustness checks, as shown in Fig. 2

[18] Moreover, the Variance Inflation Factors are satisfactory (around 1) when estimating the innovation efficiency including the reverse mills ratio but without the interaction with dynamics. This reduces concerns about multi-collinearity.

6. Discussion and conclusion

This study makes important theoretical and empirical contributions to the ongoing discussion on the optimal policy interventions to foster and support innovation. More precisely, it analyses the impacts of regulation and formal standards on firms' innovation efficiency in different market environments. Previous studies have, theoretically and empirically, focused on environmental regulation (e.g. Palmer et al., 1995; Porter and van der Linde, 1995; Majumdar and Marcus, 2001) or barriers of innovation (e.g. Galia and Legros, 2004; D'Este et al., 2012; Blanchard et al., 2013) without explicitely distinguishing between regulation and formal standardization. Our research links both streams of literature. Furthermore, by using the theoretical concepts of regulatory capture and information asymmetry, we argument that regulation and formal standardization have different effects on a firm's innovation efficiency in the context of different market environments.

Our empirical findings show that, in low uncertain markets, firms' innovation efficiency suffers more from standards as barriers to innovation, whereas regulations have a positive influence. In the case of highly uncertain markets, this relationship is inverted.

Our results are consistent with the hypothesis that formal standardization is much more prone to regulatory capture in markets with low uncertainty. We argue, that these rather mature markets are characterized by a more stable technical infrastructure which gives more opportunities for the limited number of standard setting firms to efficiently influence a market's technological infrastructure and create strong path dependencies. Such behaviour can lead to high compliance and consequently innovation costs for all other firms, which has a negative effect on their overall innovation efficiency. Regulation has a positive effect on firms' innovation efficiency in markets of low uncertainty. One possible explanation might be that regulations are less susceptible to regulatory capture. Furthermore, in markets with low uncertainty, the information asymmetry – and therefore the probability of misfits between regulations and the underlying technologies – are much lower in comparison with highly uncertain markets. Combining these arguments, regulations might be helpful in more mature markets as they create transparent and non-discriminating rules.

In case of high market uncertainty, we find the opposite effects. Highly uncertain markets are often characterized by an unstable and fast changing technical environment, in which different technological paths compete with each other. In such markets, information asymmetries that increase the probability of a potential misfit between regulations or formal standards and the underlying market technologies increase drastically. This effect is more distinct in relation to regulations as they stem from a top-down legislative process, contrary to formal standards which are derived from a process driven mainly by the market (i.e. firms) and are therefore more closely connected to the requirements of the underlying technology established in the markets. As a result, regulation has a negative impact on a firm's innovation efficiency in highly uncertain markets. Notably, formal standards have a positive effect on firms' innovation efficiency. One possible explanation might be that formal standards decrease technological uncertainty as they give direction for further technological developments. Furthermore, in markets characterized by a high level of uncertainty, there are not yet established links between standards and regulations. Consequently, the principle of regulatory relief does not function yet and the efforts to comply with the emerging regulatory framework might increase significantly, whereas standards have a more positive guiding effect than a negative cost creating effect on companies' innovation efforts.

Our results have far-reaching implications for innovation policy. They show the partially opposite impact of regulation and formal standardization in different market environments. Hence, to maximize social welfare, policy makers have to take into account the different effects of regulation and formal standards in different market environments. While regulation seems to be very fruitful in more mature (i.e. technologically less uncertain) markets, self-regulation in the form of standardization has to be protected against the threats of regulatory capture, i.e. specifying standards in order to achieve a competitive advantage for a minority group of firms at the expense of the majority of firms that may have to adopt these standards. On the contrary, in uncertain or more emerging markets, regulators may promote innovation by pushing the use of formal standardization as a coordination instrument. Finally, we interpret our results as evidence for the need of a closer coordination between government-driven regulation and industry-driven standardization in order to exploit synergies and to minimize inefficiencies generated by regulatory capture on the one hand, and information asymmetry on the other hand.

Our analysis faces several limitations. From an empirical point of view, we are measuring productivity in terms of how much input (innovation expenses) is needed to achieve a specific innovation output (introduce a new product or sales of innovative products). Similar definitions are often implemented in the economic literature (e.g. Catozzella and Vivarelli, 2014; Gao and Chou, 2015). However, we acknowledge that several aspects of productivity are not captured by our operational definition of productivity. Other measures of productivity more related to the innovation production process (e.g. duration of research projects, number of patents, time of researchers allocated to deal with standardization or regulation) could enhance our analysis on productivity. This work is left for future research. Looking at the operational definition of uncertainty we note that this measure focuses on technological aspects and partially captures the different sources of uncertainty in the markets. We believe that a more accurate measurement of market uncertainty especially for the demand side may better qualify the influence of institutional instruments, such as regulations or self-regulations via standards, on innovation. Additionally, our analysis is based on a cross-sectional dataset, making it difficult to fully evaluate for the long-term impact of regulations or standards. However, we note that the impact of regulation and standards are evaluated between 2008 and 2010, while innovation costs refer to 2010 only, allowing for a lagged relationship between the independent factors and the dependent variable. Additionally, even if there is considerable heterogeneity across firms and across sectors, the average duration of research projects is below 24 months (Djellal and Gallouj 2001; Swink et al., 2006) and panel studies on our dataset show that innovation behaviour is permanent to a very large extent (Peters, 2009). Future research should address potential causality issues when appropriate data is available. Another interesting research question is to investigate how firms that are engaged in standardization do benefit of influencing the standards.

From a theoretical point of view, our model establishes a connectedness between regulation, standardization, and innovation on a general level. Nevertheless, previous research has addressed the point that the interrelation of regulatory instruments might differ between countries (e.g. Prakash and Potoski, 2012; Berliner and Prakash, 2013). For further validation, upcoming research has to replicate our approach on an international level.

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Appendix A.

Formal derivation of hypotheses

Based on the conceptual considerations outlined in the theoretical section, using simple algebra we show how we derive formally the hypotheses.

The costs for innovation generated by regulation (IC_r) are defined as the sum of information asymmetries (A_r) and regulatory capture costs (RC_r). Similarly, costs for innovation caused by standards (IC_s) are the sum of costs due to information asymmetries (A_s) and regulatory capture (RC_s).

If A_r is equal to A_s and $RC_r < RC_s$ when uncertainty is low ($\theta = \text{low}$), then the total costs generated by regulation are lower than the costs caused by standards. In formula: $IC_r < IC_s | \theta = \text{low}$.

$$\left.\begin{array}{r} IC_r = A_r + RC_r \\ IC_s = A_s + RC_s \\ RC_r < RC_s | \theta = \text{low} \\ A_r = A_s | \theta = \text{low} \end{array}\right\} \rightarrow IC_r < IC_s | \theta = \text{low}$$

When uncertainty is high $\left(\theta = \text{high}\right)$ the relation is reversed.

If RC_r is equal to RC_s and $A_r > A_s$ when uncertainty is high ($\theta = \text{high}$), then the total costs caused by regulation are higher than the costs for innovation driven by standards. In formula: $IC_r > IC_s | \theta = \text{high}$

$$\left.\begin{array}{r} IC_r = A_r + RC_r \\ IC_s = A_s + RC_s \\ RC_r = RC_s | \theta = \text{high} \\ A_r > A_s | \theta = \text{high} \end{array}\right\} \rightarrow IC_r > IC_s | \theta = \text{high}$$

Question Q.1: What effect did the following obstacles possibly have to your innovation activities during 2008 to 2010?

(Multiple responses possible).

	Duration of Innovation projects have been extended	Innovation projects have been ended or discontinued	Innovation projects have been not started in the first place	not relevant
Legal restrictions	☐	☐	☐	☐
Industry standards and norms	☐	☐		☐

Source: Aschhoff et al. (2013, p. 308).

Question Q.2: Please describe how following characteristics describe the market environment you are active in.

(Multiple responses possible)

	Strongly agree	Agree	Disagree	Strongly disagree
The technological development is hard to predict	☐	☐	☐	☐
Customers have problems to evaluate the benefits of a product in advance	☐	☐	☐	☐

Source: Aschhoff et al. (2013, p. 304).

Table A1
Pearson's Correlation Table.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	Standards	1.00																									
2	Regulation	0.45***	1.00																								
3	No uncert.	−0.03	−0.02	1.00																							
4	Low uncert.	−0.02	−0.01	−0.23***	1.00																						
5	Medium uncert.	0.03*	0.01	−0.28***	−0.64***	1.00																					
6	High uncert.	0.00	0.01	−0.12***	−0.28***	−0.34***	1.00																				
7	Empl. (ln)	0.08***	0.09***	0.00	0.10***	−0.02	−0.10***	1.00																			
8	Group	0.07***	0.09***	0.01	0.05***	−0.01	−0.06***	0.50***	1.00																		
9	Local market	−0.09***	−0.05***	0.10***	−0.04*	−0.05***	0.04**	−0.20***	−0.16***	1																	
10	National market	0.04**	0.02	−0.08***	0.00	0.05***	−0.02	0.08***	0.05***	−0.78***	1																
11	EU market	0.07***	0.05**	−0.01	0.03	−0.01	−0.03	0.11***	0.09***	−0.19***	−0.26***	1															
12	other markets	0.02	0.03	−0.04**	0.04**	0.00	−0.03	0.12***	0.12***	−0.19***	−0.26***	−0.07***	1.00														
13	0 comp.	−0.01	−0.03	0.26***	−0.01	−0.11***	−0.05**	−0.05**	0.00	0.16***	−0.13***	−0.03	−0.03	1.00													
14	1–5 comp.	0.03*	0.04*	−0.035*	0.06***	0.01	−0.06***	0.06***	0.06***	−0.04*	−0.03	0.05**	0.08***	−0.20***	1.00												
15	6–10 comp.	0.01	0.00	−0.07***	0.01	0.03	−0.01	0.07***	0.04*	−0.06***	0.04**	0.03*	−0.01	−0.14***	−0.43***	1.00											
16	11–15 comp.	−0.01	−0.02	−0.02	−0.028	0.03	0.01	0.01	−0.01	−0.02	0.02	−0.01	0.00	−0.07***	−0.23***	−0.16***	1.00										
17	16–50 comp.	0.01	0.01	−0.02	0.01	0.01	0.00	−0.01	−0.03	−0.03*	0.06***	−0.03	−0.03	−0.08***	−0.25***	−0.18***	−0.09***	1.00									
18	50+ comp.	−0.04**	−0.03*	−0.01	−0.07***	0.00	0.11***	−0.12***	−0.09***	0.05**	0.00	−0.06***	−0.06***	−0.11***	−0.34***	−0.24***	−0.13***	−0.14***	1.00								
19	% educated labour force	0.00	0.02	−0.08***	−0.06***	0.05**	0.07***	−0.16***	−0.02	−0.19***	0.13***	0.04**	0.06***	−0.03*	0.03*	0.00	0.00	0.01	−0.02	1.00							
20	No R&D	−0.16***	−0.13***	0.11***	−0.03	−0.05**	0.02	−0.26***	−0.18***	0.38***	−0.2***	−0.17***	−0.18***	0.13***	−0.13***	−0.08***	0.02	0.02	0.15***	−0.26***	1.00						
21	Occasionally R&D	0.135***	0.12***	−0.08***	0.01	0.05**	−0.01	0.27***	0.19***	−0.34***	0.15***	0.18***	0.19***	−0.11***	0.11***	0.07***	−0.03	−0.02	−0.12***	0.24***	−0.77***	1.00					
22	Continuous R&D	0.05**	0.02	−0.06***	0.03	0.01	−0.01	0.02	0.00	−0.11***	0.09***	0.01	0.01	−0.05**	0.04**	0.02	0.01	−0.01	−0.05**	0.05***	−0.44***	−0.24***	1.00				
23	Cooperation Science and Technology	0.12***	0.09***	−0.07***	0.02	0.02	0.00	0.22***	0.15***	−0.26***	0.11***	0.14***	0.15***	−0.07***	0.09***	0.04*	−0.02	−0.01	−0.09***	0.26***	−0.55***	0.54***	0.08***	1.00			
24	Cooperation Market	0.11***	0.07***	−0.05**	0.00	0.03	−0.01	0.15***	0.13***	−0.20***	0.1***	0.11***	0.08***	−0.06***	0.08***	0.02	−0.01	−0.02	−0.07***	0.19***	−0.38***	0.38***	0.05**	0.53***	1.00		
25	Cooperation Other firms	0.14***	0.11***	−0.09***	0.03*	0.02	0.00	0.24***	0.22***	−0.19***	0.07***	0.11***	0.14***	−0.06***	0.06***	0.05***	−0.04**	0.01	−0.08***	0.16***	−0.44***	0.44***	0.06***	0.59***	0.50***	1.00	
26	Subsides	0.09***	0.06***	−0.09***	−0.01	0.05**	0.01	0.12***	0.05**	−0.27***	0.12***	0.15***	0.14***	−0.07***	0.09***	0.03	−0.02	−0.01	−0.09***	0.29***	−0.55***	0.55***	0.07***	0.65***	0.40***	0.39***	1

Correlation with sectors are available upon request.

Table A2
Heckman estimates for different specifications.

	(1)	(2)	(3)	(4)	(5)
Innovation Costs per employee (ln)					
1.Standards	0.301** (2.05)	0.298** (2.04)	0.878 (1.56)	1.090** (2.44)	1.011** (2.29)
1.Regulation	0.335** (2.17)	0.332** (2.16)	−1.039** (−2.57)	−1.157** (−3.01)	−0.963** (−2.52)
Size	−0.0820*** (−3.45)	−0.0802*** (−3.37)	−0.0792*** (−3.35)	−0.128*** (−5.46)	−0.151*** (−6.51)
Group	0.145* (1.92)	0.147* (1.95)	0.143* (1.90)	0.127* (1.75)	0.136* (1.87)
Education	0.0156*** (10.51)	0.0155*** (10.49)	0.0156*** (10.52)	0.0116*** (8.16)	0.00899*** (6.37)
Local	Ref.	Ref.	Ref.	Ref.	Ref.
National	0.584*** (6.39)	0.582*** (6.36)	0.583*** (6.38)	0.493*** (5.57)	0.494*** (5.71)
EU	1.128*** (8.98)	1.130*** (8.99)	1.134*** (9.01)	0.966*** (7.90)	0.936*** (7.79)
International	1.110*** (8.52)	1.110*** (8.53)	1.103*** (8.48)	0.914*** (7.11)	0.899*** (7.25)
No Uncertainty		Ref.	Ref.	Ref.	Ref.
Low Uncertainty		0.0564 (0.41)	−0.00684 (−0.05)	−0.0208 (−0.15)	−0.0790 (−0.58)
Medium Uncertainty		0.131 (0.98)	0.0699 (0.50)	0.0449 (0.33)	−0.0104 (−0.08)
High Uncertainty		0.152 (0.96)	0.0990 (0.60)	0.0844 (0.53)	0.0131 (0.08)
Stand.#L. uncert.			−0.610 (−1.00)	−0.825* (−1.65)	−0.744 (−1.50)
Stand.#M. uncert.			−0.477 (−0.80)	−0.759 (−1.56)	−0.769 (−1.60)
Stand.#H. uncert.			−1.387** (−1.98)	−1.805** (−2.99)	−1.727** (−3.01)
Reg.#L. uncert.			1.515** (3.21)	1.552*** (3.47)	1.333** (2.98)
Reg.#M. uncert.			1.326** (2.84)	1.397** (3.14)	1.219** (2.77)
Reg.#H. uncert.			1.959*** (3.59)	1.876*** (3.55)	1.644** (3.17)
No R&D				Ref.	Ref.
Discontinuous R&D				0.918*** (11.92)	0.638*** (8.00)
Continuous R&D				−0.0838 (−0.95)	−0.203** (−2.32)
Subsides					0.428*** (5.85)
Science Coop.					0.0315 (0.40)
Market Coop.					0.106 (1.37)
Other firms Coop.					0.326*** (4.48)
_cons	6.265*** (38.07)	6.175*** (30.53)	6.225*** (30.58)	6.174*** (30.06)	6.313*** (31.35)
Innovation active firms					
Size	0.224*** (12.29)	0.229*** (12.47)	0.229*** (12.49)	0.231*** (12.51)	0.230*** (12.48)
Group	0.0675 (1.18)	0.0700 (1.23)	0.0708 (1.24)	0.0713 (1.25)	0.0705 (1.23)
Education	0.0100*** (8.77)	0.00998*** (8.73)	0.00998*** (8.74)	0.0100*** (8.77)	0.00998*** (8.75)
Local	Ref.	Ref.	Ref.	Ref.	Ref.
National	0.408*** (7.90)	0.403*** (7.78)	0.403*** (7.78)	0.400*** (7.71)	0.402*** (7.76)
EU	0.813*** (7.04)	0.822*** (7.06)	0.822*** (7.07)	0.820*** (7.08)	0.819*** (7.07)
International	0.613*** (5.36)	0.605*** (5.28)	0.605*** (5.28)	0.607*** (5.30)	0.606*** (5.29)
0 comp.	Ref.	Ref.	Ref.	Ref.	Ref.
1–5 comp.	0.673*** (6.39)	0.599*** (5.54)	0.598*** (5.53)	0.607*** (5.59)	0.606*** (5.57)
6–10 comp.	0.634*** (5.79)	0.550*** (4.90)	0.547*** (4.87)	0.558*** (4.95)	0.555*** (4.92)
11–15 comp.	0.467*** (3.70)	0.378** (2.94)	0.373** (2.91)	0.376** (2.94)	0.372** (2.90)
16–50 comp.	0.516*** (4.31)	0.437*** (3.58)	0.436*** (3.57)	0.446*** (3.65)	0.447*** (3.65)
50+ comp.	0.327** (2.88)	0.242** (2.07)	0.239** (2.05)	0.251** (2.14)	0.249** (2.11)
No Uncertainty		Ref.	Ref.	Ref.	Ref.
Low Uncertainty		0.198** (2.36)	0.200** (2.39)	0.199** (2.37)	0.197** (2.36)
Medium Uncertainty		0.333*** (4.04)	0.336*** (4.08)	0.334*** (4.06)	0.334*** (4.05)
High Uncertainty		0.354*** (3.63)	0.357*** (3.66)	0.358*** (3.67)	0.356*** (3.65)
_cons	−1.670*** (−12.51)	−1.850*** (−12.75)	−1.850*** (−12.74)	−1.864*** (−12.76)	−1.859*** (−12.71)
LL	−6065.7	−6055.3	−6048.5	−5937.2	−5890.6
Rho	0.310	0.307	0.315	0.349	0.333
Wald test of Rho = 0: Chi2	33.51	32.36	34.09	34.34	29.50
Prob > Chi2	7.09e-09	1.28e-08	5.25e-09	4.64e-09	5.59e-08
Observations	4,027	4,027	4,027	4,027	4,027
Censored	1,773	1,773	1,773	1,773	1,773
Uncensored	2,254	2,254	2,254	2,254	2,254
Correct predictions	0.462	0.461	0.461	0.460	0.461

t statistics in parentheses.
Notes: Robust standards errors; Industry dummies are included in both equations but not reported; Prediction is correct if innovator gets a prediction above the observed average of potential innovation.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

Table A3
Heckman estimates of ratio of innovative sales on innovation costs for different specifications.

	(1)	(2)	(3)	(4)	(5)
Innovation efficiency (Ln)					
St. ext.	−0.216 (−1.19)	−0.205 (−1.14)	−1.230 (−1.22)	−1.365 (−1.51)	−1.277 (−1.34)
Reg. ext.	−0.272 (−1.34)	−0.275 (−1.35)	2.413** (2.48)	2.417** (2.35)	2.217** (2.18)
Size	0.0556** (1.97)	0.0560** (1.99)	0.0544* (1.91)	0.0814*** (2.83)	0.102*** (3.51)
Group	0.0905 (0.97)	0.0860 (0.92)	0.0888 (0.95)	0.0984 (1.06)	0.0673 (0.73)
Education	−0.00696*** (−3.62)	−0.00687*** (−3.59)	−0.00709*** (−3.68)	−0.00504*** (−2.67)	−0.00256 (−1.33)
Local	ref.	ref.	ref.	ref.	ref.
National	−0.0670 (−0.53)	−0.0604 (−0.48)	−0.0628 (−0.50)	−0.0481 (−0.39)	−0.0642 (−0.52)
EU	−0.255 (−1.56)	−0.250 (−1.53)	−0.240 (−1.45)	−0.183 (−1.12)	−0.175 (−1.07)
International	−0.325* (−1.94)	−0.320* (−1.92)	−0.319* (−1.90)	−0.261 (−1.57)	−0.239 (−1.45)
No Uncertainty		ref.	ref.	ref.	ref.
Low Uncertainty		0.00448 (0.02)	0.0567 (0.30)	0.0570 (0.30)	0.126 (0.67)
Medium Uncertainty		−0.134 (−0.67)	−0.0620 (−0.33)	−0.0507 (−0.27)	0.0101 (0.05)
High Uncertainty		−0.00793 (−0.04)	0.0851 (0.40)	0.0868 (0.41)	0.160 (0.77)
Stand.#L. uncert.			1.287 (1.24)	1.385 (1.49)	1.284 (1.31)
Stand.#M. uncert.			0.925 (0.89)	1.094 (1.16)	1.062 (1.08)
Stand.#H. uncert.			1.591 (1.45)	1.822* (1.80)	1.665 (1.59)
Reg.#L. uncert.			−2.709*** (−2.68)	−2.701** (−2.54)	−2.482** (−2.36)
Reg.#M. uncert.			−2.744*** (−2.70)	−2.713** (−2.54)	−2.526** (−2.39)
Reg.#H. uncert.			−3.674*** (−3.50)	−3.562*** (−3.22)	−3.266*** (−3.01)
No R&D				ref.	ref.
Discontinuous R&D				−0.414*** (−3.83)	−0.177 (−1.53)
Continuous R&D				0.321*** (2.62)	0.420*** (3.43)
Subsides					−0.395*** (−4.64)
Science Coop.					−0.135 (−1.40)
Market Coop.					0.0506 (0.52)
Other firms Coop.					−0.228** (−2.40)
_cons	2.158*** (9.03)	2.191*** (7.23)	2.140*** (6.96)	2.123*** (6.69)	2.022*** (6.28)
Innovation active firms					
Size	0.212*** (10.69)	0.217*** (10.83)	0.217*** (10.82)	0.217*** (10.82)	0.217*** (10.82)
Group	0.0640 (0.99)	0.0661 (1.02)	0.0666 (1.03)	0.0667 (1.03)	0.0662 (1.02)
Education	0.0121*** (9.52)	0.0121*** (9.49)	0.0121*** (9.49)	0.0121*** (9.50)	0.0121*** (9.49)
Local	ref.	ref.	ref.	ref.	ref.
National	0.490*** (8.40)	0.484*** (8.28)	0.484*** (8.28)	0.484*** (8.27)	0.484*** (8.29)
EU	0.904*** (7.26)	0.910*** (7.25)	0.910*** (7.25)	0.911*** (7.26)	0.910*** (7.26)
International	0.738*** (6.01)	0.727*** (5.92)	0.726*** (5.91)	0.726*** (5.92)	0.726*** (5.91)
0 Comp.	ref.	ref.	ref.	ref.	ref.
1–5 comp.	0.795*** (6.45)	0.714*** (5.62)	0.716*** (5.63)	0.719*** (5.66)	0.718*** (5.64)
6–10 comp.	0.730*** (5.72)	0.639*** (4.85)	0.640*** (4.86)	0.643*** (4.89)	0.641*** (4.87)
11–15 comp.	0.529*** (3.55)	0.431*** (2.82)	0.431*** (2.83)	0.434*** (2.85)	0.431*** (2.83)
16–50 comp.	0.606*** (4.34)	0.521*** (3.64)	0.522*** (3.65)	0.525*** (3.68)	0.525*** (3.67)
50+ comp.	0.354*** (2.62)	0.266* (1.92)	0.268* (1.93)	0.272* (1.96)	0.271* (1.94)
No Uncertainty		ref.	ref.	ref.	ref.
Low Uncertainty		0.285*** (2.95)	0.286*** (2.97)	0.286*** (2.96)	0.286*** (2.96)
Medium Uncertainty		0.415*** (4.36)	0.417*** (4.38)	0.417*** (4.38)	0.417*** (4.38)
High Uncertainty		0.422*** (3.76)	0.423*** (3.78)	0.423*** (3.78)	0.423*** (3.78)
_cons	−1.964*** (−13.01)	−2.213*** (−13.42)	−2.216*** (−13.42)	−2.219*** (−13.43)	−2.218*** (−13.42)
LL	−4750.0	−4738.5	−4728.7	−4699.8	−4677.2
Rho	−0.144	−0.134	−0.150	−0.158	−0.151
Wald test of Rho = 0: Chi2	3.353	3.155	3.513	3.679	3.086
Prob > Chi2	0.0671	0.0757	0.0609	0.0551	0.0790
Observations	3,444	3,444	3,444	3,444	3,444
Censored	1,773	1,773	1,773	1,773	1,773
Uncensored	1,671	1,671	1,671	1,671	1,671
Correct predictions	0.378	0.379	0.379	0.379	0.379

t statistics in parentheses.
Notes: Robust standards errors; Industry dummies are included in both equations but not reported; Prediction is correct if innovator gets a prediction above the observed average of potential innovation.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

Table A4
OLS estimates of ratio of innovative sales on innovation costs (only firms with positive innovation expenditures).

	(1)
innovative sales on innovation costs (ln)	
St. ext.	−1.253 (−1.31)
No Uncertainty	ref.
Low Uncertainty	0.159 (0.85)
Medium Uncertainty	0.0574 (0.31)
High Uncertainty	0.203 (0.98)
Stand.#L. uncert.	1.258 (1.28)
Stand.#M. uncert.	1.037 (1.05)
Stand.#H. uncert.	1.648 (1.57)
Reg. ext.	2.203** (2.15)
Reg.#L. uncert.	−2.458** (−2.31)
Reg.#M. uncert.	−2.515** (−2.36)
Reg.#H. uncert.	−3.246*** (−2.96)
Size	0.123*** (4.61)
Group	0.0736 (0.79)
Education	−0.00134 (−0.75)
Local	ref.
National	0.0110 (0.10)
EU	−0.0717 (−0.48)
International	−0.146 (−0.93)
No R&D	ref.
Discontinuous R&D	−0.171 (−1.46)
Continuous R&D	0.426*** (3.45)
Subsides	−0.393*** (−4.58)
Science Coop.	−0.136 (−1.39)
Market Coop.	0.0488 (0.49)
Other firms Coop.	−0.232** (−2.41)
_cons	1.657*** (6.98)
Adjusted R2	0.145
Observation	1,671

t statistics in parentheses.
Notes: Robust standards errors; Industry dummies are included but not reported.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

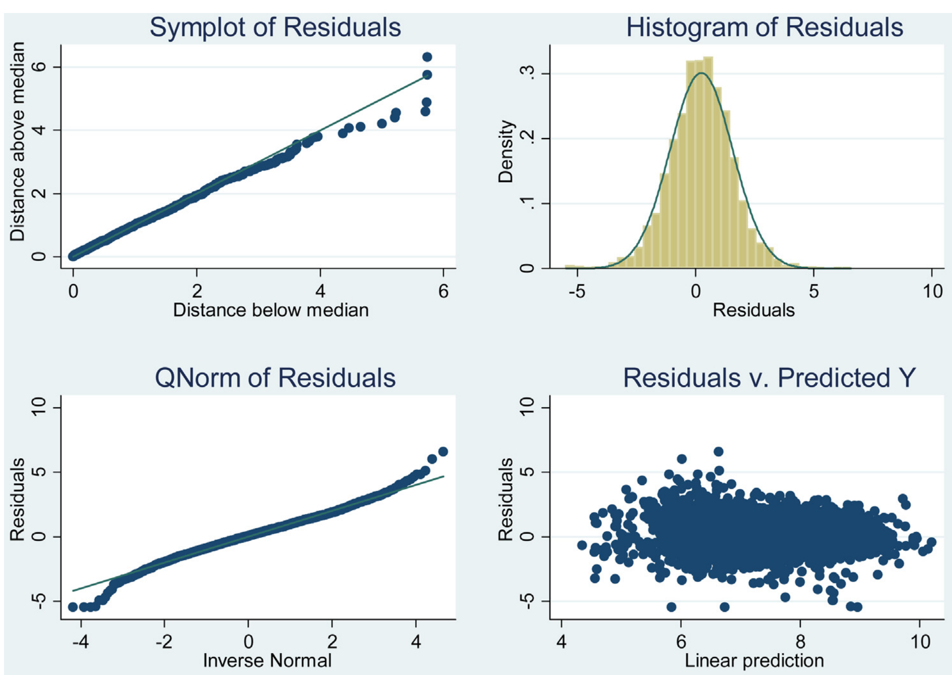

Fig. A1. Residuals analysis.

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