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Environmental Innovation and Firm Profitability – An Analysis with Respect to Firm Size

Environmental Innovation and Firm Profitability - An Analysis with Respect to Firm Size

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Abstract

This paper investigates the effect of environmental innovations on firm profitability with respect to differences between small and medium-sized (SME) and large (LE) enterprises. Using data from the Mannheim Innovation Panel (MIP) 2015, results show that, in general, SME benefit more from environmental innovations than LE. This effect is particularly strong for resource efficiency-improving innovations induced by regulation. These environmental innovations are significantly related to an increase in profits of SME, whilst related to a decrease in profits of LE. A robustness check with data from the MIP 2009, however, does not confirm this result as the effect for LE is insignificant and differences between the two groups cannot be found in this survey wave. A reason why negative effects for LE are observed in the MIP 2015 - but not in the MIP 2009 - might be that most LE had already exploited the potentials of environmental innovations when they were surveyed in the MIP 2015. This is supported by evidence suggesting that size-related differences in the MIP 2015 are driven by a negative relationship between LE's profits and environmental innovations related to externalities that were reduced by innovations in periods before.

Keywords: Firm Behavior, Firm Size, Porter hypothesis, Environmental Technology Adaption, Technological Innovation, Environmental Regulation
JEL Classification Numbers: D22, L25, Q52, Q55, Q58

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1 Introduction

Climate change, resource scarcity and an increasing environmental pollution call for investments in environmentally friendly technologies. Porter (1991) and Porter & van der Linde (1995) argue that regulation[1] can stimulate necessary environmental innovations (EI). However, a common perspective by economists is that regulation restricts firms and shifts away productive investments to pollution abatement costs (Palmer et al. 1995, Testa et al. 2011). Porter (1991) and Porter & van der Linde (1995) also claim that this is not necessarily the case. Environmental regulation can additionally increase firm profitability, as environmental pollution may result from an inefficient use of resources and environmental regulation can point out potential technological improvements, which increase productivity. Rexhäuser & Rammer (2014) prove that the validity of this assumption depends on whether regulation stimulates resource efficiency improvements, defined here as a reduction of energy, water or other material use per unit of output. They show empirically that only environmental process innovations which improve resource efficiency including innovations triggered by regulation are related to an increase, while other environmental process innovations are related to a decrease in firm profitability.

I propose that, aside from resource efficiency improvements, firm size additionally affects profitability gains of regulation-induced environmental innovations. I assume this because smaller firms show different innovation patterns in comparison to larger firms (Acs & Audretsch 1988). Those differences may also exist for environmental innovations (Klewitz & Hansen 2014). Furthermore, Becker et al. (2013) and Evans (1986) find that regulation imposes less pollution abatement costs on smaller firms. Moreover, they often lack information about potential resource efficiency improvements (Constantinos et al. 2010, Rahbauer et al. 2016). If environmental regulation signals firms how to increase efficiency (Anderson & Ullah 2014, Ambec et al. 2013), the benefits from information gains could be higher in smaller firms, as there is less knowledge about potential resource efficiency improvements. Therefore, the effect of especially regulation-induced and resource efficiency-improving environmental innovations on firm profitability could be larger for smaller firms. However, the role of firm size for profitability gains of environmental innovations has not been analyzed yet.

This paper attempts to fill this gap. I look at four types of environmental innovation, fol-

[1] This study summarizes all policy instruments defined as command-and-control instruments or market-based instruments as environmental regulations and does not distinguish between both kinds of policy instruments.

lowing Rexhäuser and Rammer (2014): *regulation-induced resource efficiency innovation, regulation-induced other environmental innovation, voluntary resource efficiency innovation and voluntary other environmental innovation*, and analyze whether their effect on firm profitability, which is measured by return on sales (ROS), depends on firm size. I apply data from two waves of the *Mannheim Innovation Panel* (MIP), consisting in total of 6,303 German firms. The MIP 2015 is used for the main analysis and the MIP 2009 additionally for robustness checks. SME are defined as firms with less than 250 employees and less than €50 Million of annual sales.

The results confirm the assumption for the MIP 2015 wave. Environmental innovations are positively correlated with ROS only in SME. Moreover, an interaction term between the logarithmized number of employees and environmental innovations reveals that the positive effect of environmental innovations significantly decreases if the number of employees increases. Differentiating between the four types of environmental innovations shows that the positive effect in SME is solely related to innovations that improve resource efficiency and are regulation-induced. Moreover, the same type of innovation has a significantly negative influence in LE. The analysis of the MIP 2009 wave also shows only positive effects for SME. However, the interaction term does not show any significant size-related differences in this period.

Increasing size-related differences between both waves can be explained by a robustness check where evidence suggests that it gets more difficult after a while for LE to find EI that are profitable. This is because, in this group former environmental innovations negatively influence the profitability of current environmental innovations if they belong to the same dimension of environmental benefits. However, most firms, of small and large size, started to implement EI in 2009, therefore no size-related differences exist in this period.

The remainder of this paper is organized as follows: Section 2 summarizes previous empirical findings regarding the Porter hypothesis and size-dependent differences between firms. Data, theoretical approach and estimation strategy are described in section 3. Section 4 presents the main findings and section 5 further robustness checks. Results and study limitations are discussed in section 6. Section 7 concludes.

2 The Porter hypothesis and size-dependent differences regarding environmental innovations

2.1 The Porter hypothesis

Studies that build on Porter (1991) and Porter & van der Linde (1995) divide their hypothesis into three versions: a weak version (A), a narrow version (B) and a strong version (C) (Ambec et al. 2013). (A) The weak version merely claims that environmental regulation spurs innovation. Several studies confirm the weak version (Jaffe & Palmer 1997, Brunnermeier & Cohen 2003, Arimura et al. 2007, Horbach 2008, Horbach et al. 2012, Ambec et al. 2013). Studies also show that larger firms are more likely to implement an environmental innovation than smaller firms (Triguero et al. 2013, Horbach et al. 2012).[2] However, these studies do not consider that LE are generally more likely to implement an innovation because of their size. (B) The narrow version postulates that ("...) flexible regulatory policies [market-based instruments] give firms greater incentives to innovate and thus are better than prescriptive forms [command-and-control instruments] of regulation" (Ambec et al. 2013, p.5).[3] According to my knowledge, there are no studies on the narrow version mentioning firm size issues. (C) The strong version states that properly designed regulations will offset compliance costs due to technological improvements (Porter 1991, Porter & van der Linde 1995). The strong version is the most relevant for firms, as it includes economic improvements. Therefore, I focus on related size-dependent issues. Empirical studies of the strong version show ambiguous results. Cohen & Tubb (2018) find in a meta-analysis of 108 studies analyzing the strong version that those employing a lagged regulatory variable as well as those observing profitability changes on a country level are more likely to confirm the strong version. Analyzing 3,618 firms based on the MIP 2009, Rexhäuser & Rammer (2014, p.145) find that "(...) the Porter hypothesis does not hold in general for its strong version, but depends on the type of environmental innovation" and resource efficiency improvements are crucial for an increase in profitability. Ghisetti & Rennings (2014) come to the same conclusion by using MIP 2009 data as explanatory variables, but dependent variables from the MIP 2011. Investigating a water withdrawal regulation in Germany, Stoever & Weche (2018) find that the regulation in question does not affect firms' overall profitability, even though it increases investments in integrated (resource efficiency-improving) technologies. Different outcomes between

2 Triguero et al. (2013) only distinguish between small and medium-sized firms.

3 Originally, the Porter hypothesis was built-up on market-based instruments (Porter & van der Linde 1995, Ambec et al. 2013).

Stoever & Weche's (2018) and Rexhäuser & Rammer's (2014) study, however, indicate that the type of environmental innovation (i.e. resource efficiency-improving vs. others) is not the only factor which influences the effect of environmental innovations on firm profitability.

2.2 Size-dependent differences

Analyzing sustainability-oriented innovation of SME, Klewitz & Hansen (2014, p.59) argue that "SME will innovate differently than larger companies because they possess distinct organizational structures and capabilities." In the following, arguments that explain why size-dependent differences exist are presented.

SME and LE differ in general by the following aspects: First, unit costs of EI might be higher in smaller firms in the presence of economies of scale (Stigler 1958, Varian & Buchegger 2004). This would affect SME profits negatively.[4] Second, innovation activities of SME and LE respond differently to the same technological and economic environment according to Winter (1984) and Acs & Audretsch (1988). For example, innovation activities of smaller firms profit more from spillovers of technological knowledge generated by others (R&D spillovers) (Acs et al. 1994). Moreover, Vossen (1998) states that SME and LE possess characteristics that lead to different relative advantages. Smaller firms, for example, may profit from shorter decision chains and a lower level of bureaucracy. Larger firms may often possess the ability to support the establishment of large R&D laboratories and the ability to spread risk over a portfolio of projects. Both, different responses to the technological and economic environment as well as different relative advantages could also be valid for environmental process innovations and may cause a difference in the profitability of EI, however, ex ante it is not possible to state which group profits more.

Regulation may affect SME and LE differently. Dean et al. (2000) consider three types of legislative asymmetries: (A) compliance asymmetries, (B) statutory asymmetries and (C) enforcement asymmetries. (A) Compliance asymmetries result from differences in compliance costs per unit of output. Compliance costs are all expenses that a firm makes in order to follow regulation.[5] An advantage for LE exists, for example, when

[4] An employee that is exclusively dedicated to environmental issues like "waste reduction" is one example here.

[5] Compliance costs include salaries of people working in compliance, time or money spent on reporting and approval costs as well as investments required to meet the regulation targets.

total compliance costs are the same for all firms. Hence, they are less per unit for LE.[6] (B) Statutory asymmetries result from an unequal legislation for smaller and larger firms. They are included in most European and German environmental laws and are supposed to level the playing field between SME and LE.[7] Thus, if properly designed, they counterbalance compliance asymmetries. (C) Enforcement asymmetries exist when environmental law is unequally enforced by firm size. From a government's perspective, environmental improvement is less costly when a large firm is enforced, which pollutes relatively more, instead of many small firms as "(...) there are sizable fixed costs [paid by the government] involved in each investigation" (Dean et al. 2000, p.59). Hence, large firms might be enforced more often as the government wants to reduce its spending. In addition, large firms might be more exposed to environmental regulation due to sector-specific differences as well. Different kinds of industries show different pollution levels and industries that cause more environmental pollution often have a higher share of LE (Constantinos et al. 2010). Becker et al. (2013) find that the net effect of all legislative asymmetries disadvantages larger firms. The study, however, considers only abatement costs. The current work aims to connect size-dependent differences of pollution abatement costs with the Porter hypothesis by analyzing whether regulation also causes a size-dependent profitability of environmental innovation.

Differences regarding the influence of regulation on resource efficiency improvements are likely because of the following issues: SME often lack knowledge regarding potential resource efficiency improvements (Constantinos et al. 2010, Mattes et al. 2015) and implement resource efficiency-improving environmental innovations less often than large firms (Mattes et al. 2017).[8] For example, in a survey dealing with compliance issues related to the British low carbon agenda with 141 SME in Derbyshire, Rahbauer et al. (2016) find that smaller firms struggle with target settings for energy consumption and waste outputs. Vernon et al. (2003) state that SME are rather reactive to environmental regulations than proactive. Accordingly, regulation may help (especially smaller) firms to overcome organizational inertia (Ambec & Barla 2002). Moreover, regulation may inform firms about resource inefficiencies (Ambec et al. 2013) and there is less knowledge about potential resource efficiency improvements in SME. Thus, regulation and regulation-related information gains may help especially SME to increase resource

[6] The issue resulting from economies of scale is comparable to the one resulting from compliance asymmetries.

[7] For example, the German Immission Control Act (BImSchG; Gesetz zum Schutz vor schädlichen Umwelteinwirkungen durch Luftverunreinigungen, Geräusche, Erschütterungen und ähnliche Vorgänge) includes special arrangements for combustion plants below a certain size.

[8] It is not stated whether this result is influenced by regulation.

efficiency and profitability.

Table 1 summarizes all differences and their effects on a diverging profitability of EI. Ex ante, the effect of general differences is ambiguous. This is because, even though economies of scale advantage larger firms, differences in the response to the technological and economic environment as well as relative advantages may offset negative effects. The effect of legislative asymmetries is also ambiguous ex ante, as each asymmetry either advantages LE or SME and it cannot be predicted which asymmetry has the strongest influence. However, Becker et al. (2013) find higher pollution abatement costs for larger enterprises. Therefore, I assume that legislative asymmetries rather advantage SME. Moreover, smaller firms should profit relatively more from regulations providing information gains related to resource efficiency improvements. Hence, regulation-induced resource efficiency innovations should show higher effects on profitability in SME compared to LE.

Table 1: Differences between SME and LE and how they affect the profitability of EI

Type of Difference	Affected EI types	Effects on profitability difference between SME and LE
General differences		
Economies of scale	all types	advantage for LE
Response to tech. & econ. environment	all types	ambiguous
Relative advantages	all types	ambiguous
Total	all types	ambiguous
Legislative asymmetries		
Compliance asymmetries	regulation	advantage for LE
Statutory asymmetries	regulation	ambiguous, rather advantage for SME
Enforcement asymmetries	regulation	advantage for SME
Total	regulation	ambiguous, rather advantage for SME
Differences regarding the influence of regulation on resource efficiency improvements	regul. & resource	advantage for SME

3 Empirical framework and data

In the following, I illustrate my empirical approach. I describe the model I use, my empirical strategy as well as the applied data. Additionally, I provide the descriptive statistics.

3.1 Model

The model I use is based on the work of Rexhäuser & Rammer (2014)[9] and analyzes the effect of EI on firm profitability. Pre-tax return on sales (ROS), defined as profits divided by return, is used to measure the latter. Moreover, the model includes firm and market-specific characteristics as additional explanatory variables. The effect of EI is analyzed with respect to product differentiation (PD), efficiency gains through regular process innovations (PC), competition intensity (CP), a firm's knowledge stock (KS), a firm's cost structure (CS) and a set of further control variables to account for sector-specific and regional heterogeneity (C). The econometric model is illustrated in equation (1):

$$ROS_{i,t} = \alpha + \beta EI_{i,t} + \gamma_1 PD_{i,t} + \gamma_2 PC_{i,t} + \gamma_3 CP_{i,t} + \gamma_4 KS_{i,t} + \gamma_5 CS_{i,t} + + \gamma_6 C_{i,t} + \epsilon_{i,t} \quad (1)$$

3.2 Empirical strategy

The empirical strategy includes two steps:

1. In the first step, I estimate whether the implementation of an environmental innovation is related to higher profits. The aim of this step is to analyze if size-specific differences exist regardless of the EI type. Accordingly, differences in the effects of resource efficiency improvements and regulation are not considered yet.

2. In the second step, I split environmental innovations into the four types—in regulation-induced as well as voluntary ones and then further into resource and other innovations: regulation & resource (RR), regulation & other (RO), voluntary & resource (VR), voluntary & other (VO). In this step, I aim to identify whether size differences differ for types of environmental innovation. Hence, the EI variable in equation (1) is replaced by four EI variables as illustrated in equation (2):[10]

$$ROS_{i,t} = \alpha_i + \beta_1 RR_{i,t} + \beta_2 RO_{i,t} + \beta_3 VR_{i,t} + \beta_4 VO_{i,t} + (...) + \epsilon_{i,t} \quad (2)$$

To observe differences between SME and LE, four different estimations are conducted in each step. The first three are based on equation (1). The first estimation includes all

9 For a detailed explanation of the model look in Rexhäuser & Rammer's (2014) study.
10 All other model variables are summarized by (...).

observations, the second analyzes only SME and the third only LE. The forth estimation is based on equation (3), which is an extension of equation (1). Firm size (S) is added here as an additional variable as well as an interaction term between firm size and environmental innovation. S is measured by the logarithmized number of employees. In the first step, the forth estimation is conducted as illustrated. In the second step, the EI interaction term is replaced by products between each innovation type and the logarithmized number of employees.

$$ROS_{i,t} = \alpha + \beta_1 EI_{i,t} + \beta_2 EI_{i,t} * S_{i,t} + \beta_3 S_{i,t} + (...) + \epsilon_{i,t} \tag{3}$$

The interpretation of the environmental innovation variable in equation (3) is different from equation (1). It measures ROS when the logarithmized number of employees is 'zero'. Thus, when the number of employees is 'one'. The coefficient of the firm size variable measures the effect on ROS in the absence of environmental innovation. The interaction term captures how the effect of environmental innovations changes when the number of employees increases.[11]

Furthermore, I use an interval-censored regression model because firms do not report the exact percentage of ROS in the MIP, but they report ROS-intervals - e.g. between 0% and 2%. Hence, the applied dependent variable is ordinal-scaled. Therefore, an ordinary least-squares (OLS) regression model cannot be used. However, as interval limits of ROS are known, an interval-censored regression can be applied (Verbeek 2008), which is best described as an ordered probit model with known interval limits. According to Wooldridge (2002), the estimated coefficients can be directly interpreted as partial effects.

3.3 Data and variable description

3.3.1 Data

German data of the *Mannheim Innovation Panel* (MIP)[12], which is an annual survey conducted in panel format by the Centre for European Economic Research (ZEW), is used.[13]

[11] I choose the logarithmized number of employees as an interaction term and not an SME-LE dummy because the extra information that the SME-LE dummy would provide is similar to the information from a comparison of the second and third estimation with a Wald test.

[12] See Peters & Rammer (2013) for details on the survey.

[13] Germany is selected for the analysis because it possesses comparatively high regulation standards in the EU (Rexhäuser & Rammer 2014). Furthermore, the environmental law of the European Union

The MIP is the German contribution to the European Commission's Community Innovation Survey (CIS) and follows its methodology. The MIP covers both manufacturing and service sectors. It is conducted as a mail survey including an option to respond online.

Only the MIP 2009 and the MIP 2015 wave include questions on environmental action. The MIP 2015 is used for the main analysis and the MIP 2009 is used for robustness checks. The sample consists of 2,691 firms from the 2015 wave and 3,612 firms[14] from the 2009 wave. The two different waves are analyzed separately because the questionnaire changed between both waves and items differ. Moreover, the number of valid observations is smaller in the MIP 2015. Therefore, analyzing both waves jointly would give a higher weight on years further back. The MIP 2015 gross sample consists of 29,370 enterprises with 7,212 firms (net sample) providing usable data. The response rate is 25%. The net sample of the MIP 2009 consists of 7,657 firms, corresponding to a response rate of 26%. Sector and size composition of both net samples do not differ significantly from respective gross samples. This indicates representativeness regarding the sector and size distribution of the German firm population (Rammer et al. 2016). However, not all observations from the net samples are included in the analysis. The applied items have a considerable number of missing values.[15] Consequently, a Heckman selection model is applied to test for a non-random sorting of firms (Heckman 1979). The inverse Mills ratio is not significant. Hence, a selection bias can be ruled out.[16]

3.3.2 Variable description

Table 2 (dependent variable) and Table 3 (independent variables) provide descriptive statistics of the model variables for all observations (ALL) as well as for SME and LE separately and for both waves. SME are defined as all firms with less than 250 employees and an annual revenue of less than €50 Million. LE are all other firms. The MIP 2015 sample contains 78% (2,093) SME and 22% (598) LE and the MIP 2009 sample contains 83.1% (3000) SME and 16.9% (612) LE.[17]

is considered to be the worldwide most extensive (Jordan 2012).

14 The number of observations differs from Rexhäuser & Rammer (2014) because of differences in the data preparation process.

15 Missing values of control variables are imputed by the sector mean of the respective size class.

16 The results of the Heckman selection model are available from the author upon request.

17 Dividing firms merely by two groups (SME and LE) allows concluding about firm size differences with respect to only one graduation. Nevertheless, only one graduation is chosen to insure sufficiently large sample sizes.

The MIP gathers information concerning ROS by asking firms about earnings before taxes (EBT) as a percentage of turnover. Firms do not have to reveal the exact number, they choose between nine intervals as illustrated in Table 2. ROS is measured at the end of the reference period (2014 for MIP 2015) and at the middle of the reference period (2013 for MIP 2015), but ROS measured at the end of the reference period is used as dependent variable. In both waves the median return on sales lies in the interval '4% to <7%' for all observations as well as for SME. For LE it lies in the interval '2% to <4%'. Hence, the median return on sales is generally higher for SME.[18]

Table 2: Summary statistics of the dependent variable.

	Size class					
Pre-tax return on sales	**LE**		**SME**		**ALL**	
	No.	Col %	No.	Col %	No.	Col %
MIP 2015						
below -5%	30	5.0	156	7.5	186	6.9
-5% to < -2%	17	2.8	68	3.2	85	3.2
-2% to < 0%	27	4.5	89	4.3	116	4.3
0% to < 2%	113	18.9	300	14.3	413	15.3
2% to < 4%	122	20.4	329	15.7	451	16.8
4% to < 7%	113	18.9	351	16.8	464	17.2
7% to < 10%	78	13.0	261	12.5	339	12.6
10% to <15%	57	9.5	230	11.0	287	10.7
15% and more	41	6.9	309	14.8	350	13.0
Total	598	100.0	2093	100.0	2691	100.0
MIP 2009						
below 0%	80	13.1	361	12.0	441	12.2
0% to < 2%	119	19.4	540	18.0	659	18.2
2% to < 4%	111	18.1	501	16.7	612	16.9
4% to < 7%	119	19.4	510	17.0	629	17.4
7% to < 10%	77	12.6	391	13.0	468	13.0
10% to < 15%	62	10.1	351	11.7	413	11.4
15% and more	44	7.2	346	11.5	390	10.8
Total	612	100.0	3000	100.0	3612	100.0

Source: MIP 2015 & MIP 2009; own calculation.

The MIP 2015 asks in a question based on the harmonized CIS questionnaire whether an **environmental process innovation** has been implemented within the last three years,

[18] According to a Pearson's chi-squared test, the distribution of ROS significantly differs between SME and LE (MIP 2015: p-value < 0.001, MIP 2009: p-value = 0.04). See Plackett (1983) for a method description of the Pearson's chi-squared test. The distribution of SME is greater at the highest and at the lowest ROS-interval; and the distribution of LE is higher in the middle of the ROS-intervals. This is in line with deviating business risks between SME and LE because SME have usually fewer projects, which can either be successful or fail. Thus, they are more likely to be found in extreme intervals.

Table 3: Summary statistics of the independent variables. SME & LE in brackets.

Variable	Wave	Timing	N (SME/LE)	Mean (SME/LE)	Std. D. (SME/LE)	Min.	Max.
Environmental innovation							
EI	2015	2012-2	2.691 (2,093/ 598)	0.57 (0.52/ 0.73)	0.50 (0.50/ 0.44)	0	1
	2009	2006-2	3,612 (3,000/ 612)	0.57 (0.55/ 0.71)	0.49 (0.50/ 0.45)	0	1
EI panel	2015	2012-2	947 (769/ 205)	0.54 (0.49/ 0.68)	0.50 (0.50/ 0.47)	0	1
	2009	2006-2	947 (769/ 205)	0.57 (0.55/ 0.68)	0.49 (0.50/ 0.47)	0	1
Same EI in both waves	both		974 (769/ 205)	0.31 (0.28/ 0.44)	0.46 (0.45/ 0.50)	0	1
Regulation	2015	2012-2	2.691 (2,093/ 598)	0.26 (0.21/ 0.43)	0.44 (0.41/ 0.49)	0	1
	2009	2006-2	3,612 (3,000/ 612)	0.23 (0.20/ 0.37)	0.42 (0.40/ 0.48)	0	1
Regulation & resource	2015	2012-2	2.691 (2,093/ 598)	0.23 (0.19/ 0.39)	0.42 (0.39/ 0.49)	0	1
	2009	2006-2	3,612 (3,000/ 612)	0.18 (0.16/ 0.32)	0.39 (0.36/ 0.47)	0	1
Regulation & other	2015	2012-2	2.691 (2,093/ 598)	0.18 (0.14/ 0.32)	0.39 (0.35/ 0.47)	0	1
	2009	2006-2	3,612 (3,000/ 612)	0.19 (0.17/ 0.33)	0.40 (0.37/ 0.47)	0	1
Voluntary & resource	2015	2012-2	2.691 (2,093/ 598)	0.25 (0.25/ 0.25)	0.43 (0.43/ 0.43)	0	1
	2009	2006-2	3,612 (3,000/ 612)	0.28 (0.27/ 0.30)	0.45 (0.45/ 0.46)	0	1
Voluntary & other	2015	2012-2	2.691 (2,093/ 598)	0.15 (0.15/ 0.17)	0.36 (0.35/ 0.37)	0	1
	2009	2006-2	3,612 (3,000/ 612)	0.21 (0.21/ 0.24)	0.41 (0.40/ 0.43)	0	1
Control variables							
Pressure of increasing input prices	2015	2012-2	2.691 (2,093/ 598)	0.31 (0.27/0.44)	0.46 (0.44/ 0.50)	0	1
	2009	[-]	[-]	[-]	[-]	[-]	[-]
Market novelty	2015	2012-2	2.691 (2,093/ 598)	0.18 (0.16/ 0.25)	0.39 (0.37/ 0.44)	0	1
	2009	2006-2	3,612 (3,000/ 612)	0.21 (0.20/ 0.29)	0.41 (0.40/ 0.45)	0	1
Cost-saving innovation	2015	2012-2	2.691 (2,093/598)	0.16 (0.13/ 0.25)	0.36 (0.34/ 0.43)	0	1
	2009	2006-2	3,612 (3,000/ 612)	0.21 (0.18/ 0.36)	0.41 (0.38/ 0.48)	0	1
Market share	2015	2014	2.691 (2,093/ 598)	0.15 (0.13/ 0.22)	0.26 (0.25/ 0.26)	<0.01	1
	2009	2008	3,612 (3,000/ 612)	0.17 (0.16/ 0.24)	0.26 (0.26/ 0.27)	<0.01	1
Competition pressure	2015	2014	2.691 (2,093/ 598)	0.59 (0.60/ 0.55)	0.49 (0.49/ 0.49)	0	1
	2009	2008	3,612 (3,000/ 612)	0.54 (0.54/ 0.57)	0.50 (0.50/ 0.49)	0	1
Use of IPR	2015	2014	2.691 (2,093/ 598)	0.26 (0.21/ 0.44)	0.44 (0.41/ 0.50)	0	1
	2009	[-]	[-]	[-]	[-]	[-]	[-]
Assets-to-sales ratio	2015	2014	2.691 (2,093/ 598)	0.38 (0.38/ 0.36)	0.71 (0.71/ 0.70)	<0.01	6.92
	2009	2008	3,612 (3,000/ 612)	0.37 (0.38/ 0.34)	0.78 (0.80/ 0.67)	<0.01	8.37
Employees (in logs)	2015	2014	2.691 (2,093/ 598)	3.67 (3.08/ 5.75)	1.60 (1.16/ 1.10)	0	8.82
	2009	2008	3,612 (3,000/ 612)	3.76 (3.28/ 6.11)	1.56 (1.18/ 0.96)	0	8.44
Firm in East Germany	2015	2014	2.691 (2,093/ 598)	0.32 (0.36/ 0.17)	0.47 (0.48/ 0.38)	0	1
	2009	2008	3,612 (3,000/ 612)	0.30 (0.34/ 0.14)	0.46 (0.47/ 0.35)	0	1

a Lagged return on sales dummies and sector dummies are excluded.
b Source: MIP 2015 & MIP 2009; own calculation.

differentiating by nine types of process-related EI. Answers are given on a three-point Likert Scale (no, minor or high environmental benefits) in 2015 and on a four-point Likert Scale (no, minor, medium or high environmental benefits) in 2009. However, the MIP does not quantify how many EI a company implemented. To estimate the effect of all environmental innovations, a dummy variable EI is generated which takes the value 'one' for all firms that implemented at least one environmental process innovation (regardless of the extent of environmental benefits) and the value 'zero' for all observations who answered "no". In both waves, 57% of all firms implemented an environmental innovation. Dividing the sample by size and wave reveals that in the MIP 2015 wave only 52% of all SME, but 73% of all LE implemented an environmental innovation. In the 2009 wave, 55% of all SME and 71% of all LE reported to be environmentally active. Hence, a large difference exists between both groups and the difference increased between both waves. A Pearson's chi-squared test confirms that the likelihood to implement an environmental innovation significantly differs between SME and LE in both waves (p-value ≤ 0.01).

In the second step of my empirical strategy, I estimate the effect of environmental innovation on firm profitability with respect to the four different types of environmental innovation. At first, I divide environmental innovations into **regulation-driven** and **voluntary**. I define environmental innovations that were implemented for the reasons of regulation standards, tax measures and expected regulations as regulation-driven.[19] All remaining environmental innovations I consider as voluntary. Thereafter, regulation-induced and voluntary innovations are divided into resource efficiency-improving and other innovations. Resource efficiency-improving EI include innovations which *"reduced energy use per unit of output"* or *"reduced material or water use per unit of output"*. Other EI include innovations that *"reduced air emissions"* (except CO_2), *"reduced water or soil pollution"*, *"reduced noise pollution"*, *"replaced fossil energy sources with renewable energy sources"* or *"replaced materials with less hazardous substitutes"*. Two further dimensions of environmental innovations are excluded from the analysis because they cannot be assigned unambiguously to either of the two types, these are EI with *"reduced CO_2 emissions"* or *"improved recycling of materials, waste or water"*.

[19] MIP 2015: All firms that reported to be at least on a medium level (four-point Likert Scale) influenced by the mentioned reasons; MIP 2009: All firms that answered with "yes".

A problem occurs in this step because the influence of regulation has not been observed independently for each dimension of environmental benefits. Table 9 in the Appendix illustrates the problem with MIP 2015 data. 768 firms (505 SME and 263 LE) are observed with both, resource efficiency-improving and other innovations, and out of them 445 firms (270 SME and 175 LE) reported that innovations were induced by regulation. Consequently, 445 observations exist in the MIP 2015 with ambiguous assignments of regulation, which is considered as a further data restriction. A robustness check conducted by Rexhäuser & Rammer (2014) indicates, however, that it does not affect the main findings whether a positive regulation status is attributed only to resource efficiency-improving innovations, only to other innovations or to both types. Also, it is likely that environmental law does not only induce resource or only other innovations within one firm. It is rather likely that both types were induced by regulation. Hence, resource and other innovations are both classified as regulation-induced in this work if a firm reported both innovation types as well as the influence of regulation.

Figure 1 illustrates the percentage of firms with different types of environmental innovation for both MIP waves. The first picture shows the number of environmental innovation for all firms. In the 2009 wave, voluntary & resource innovations (VR) are the most widespread with 28% and regulation & resource innovation (RR) the rarest with 18%. 19% of all firms introduced a regulation & other innovation (RO) and 21% a voluntary & other innovation (VO). In the 2015 wave, only 25% introduced a voluntary & resource innovation, only 18% a regulation & other innovation and 15% a voluntary & other innovation. Hence, most types of environmental innovation decreased from 2009 to 2015. However, regulation & resource innovations increased up to 23%. The second picture shows only SME. In both waves, voluntary & resource innovations are the most common in SME. In the 2009 wave, 27% of all SME implemented one and in 2015 at least every fourth SME introduced one. Additionally, the second largest share were voluntary & other innovations (21%) for the MIP 2009. That changed in the 2015 wave. Voluntary & other innovations dropped down to 15% and SME with regulation & resource innovations increased from 16% to 19%. The third picture shows LE. In the 2009 wave, regulation & other innovations were the most prevalent (33%). In the 2015 wave, regulation & resource innovations were the most common (39%). Like for SME, only the share of this type increased between both waves. Moreover, LE show a higher share of regulation-induced environmental innovations in comparison to SME. This can have different reasons. First, LE generally show a higher share of any innovative activity, which simply reflects that the probability that a certain event occurs within a certain period of time tends to increase by the size of an organization. In addition, LE might be more exposed to regulation than SME, or LE may implement more often environmental innovations in response to regulation.

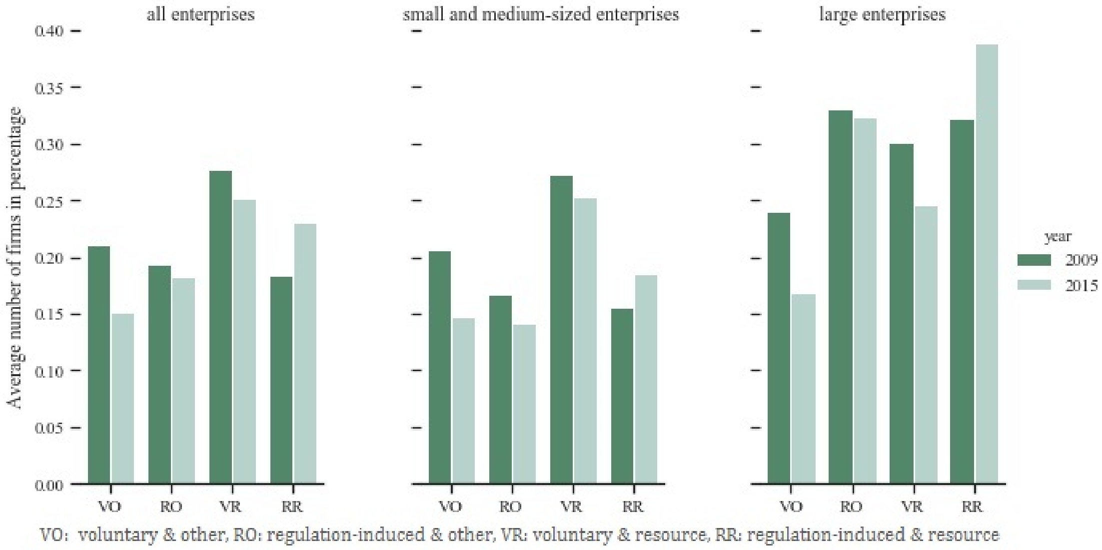

Figure 1: Average number of firms with an environmental innovation by different innovation types (Source: MIP 2015 & MIP 2009; own calculation).

The following control variables are included in the empirical model:[20] The dummy variable **market novelty** controls for price setting advantages due to product differentiation (PD). It takes the value 'one' if a firm introduced at least one product that is new to the market and 'zero' otherwise. On average, 16% of all SME and 27% of all LE introduced a market novelty in the MIP 2015 wave. Moreover, process innovations (PC) decrease costs and increase profits due to improvements in the firm-specific cost structure (CS). Accordingly, the dummy variable **cost-saving innovation** captures all firms which implemented at least one cost-reducing process innovation in the respective period as 'one' and 'zero' otherwise. 25% of all LE and only 13% of all SME are observed with a cost-reducing process innovation (MIP 2015). Besides, not only environmental innovations declined between both waves, but also cost-saving innovations as well as market novelties. A

[20] Only descriptive statistics of the main analysis (MIP 2015) are reported in the text.

firm's knowledge stock (KS) is difficult to measure. Fortunately, firms that produce novel knowledge are likely to protect their knowledge by means of intellectual property rights (IPR) while other firms do not. Hence, firms' use of IPR is taken as a proxy for KS. Therefore, the dummy variable **use of IPR** takes the value 'one' if a firm used intellectual property rights and it takes the value 'zero' otherwise. Information about the use of IPR is only provided in the MIP 2015. 44% of all LE but only 21% of all SME reported to use intellectual property rights. Furthermore, **competition pressure (CP)** is measured by a dummy which is 'one' if at least three of the following questions were answered with "applies fully" or "applies mainly"[21]: 1. *"Are products and services from competitors easily substituted by those of your enterprise?"* 2. *"Is the entry of new competitors a major threat to your market position?"* 3. *"Are competitors' actions difficult to predict?"* 4. *"Is costumer demand development difficult to predict?"* 5. *"Is your firm facing strong competition from abroad?* 6. *"Do price increases lead to immediate loss of clients?"*. In the MIP 2015, 60% of all SME reported a high competition intensity, 5% more than LE.

In order to take into account sector-specific differences, 21 sector dummies based on a two-digit NACE code are integrated in the econometric model as well.[22] Firm size is included in every estimation since economies of scale may also affect regular unit costs. The variable is measured by the natural logarithm of employees at full-time equivalents at the end of the reference period. Another driver—especially of resource efficiency improvements—are increased (relative) energy and material prices (Rexhäuser & Rammer 2014, Popp 2002, Newell et al. 1999, Jaffe & Stavins 1995). Thus, the effect of environmental innovations on profitability could be biased due to impacts of resource price changes. The dummy variable **pressure of increasing input prices** controls for this, which is only reported in the MIP 2015. It is 'one' if a firm stated that cost-saving motivations were "high" or "medium" important for introducing an EI and 'zero' otherwise. On average, 27% of all SME and 44% of all LE reported increasing input prices as a motivation. Furthermore, firm profitability may be influenced by a firm's **market share** because it increases market power and allows setting higher price (Buzzell et al. 1975).[23] According to the MIP 2015,

[21] The two highest answers on a four-point Likert scale.
[22] The sectors are presented in Table 8 in the Appendix.
[23] Besides, market share is related to competition intensity (CP) and is an indicator for productivity (Ravenscraft 1983, Foster et al. 2008, Shepherd 1972), and therefore, related to the firm's cost structure (CS) as well.

LE possess a market share of 22% and SME of 13% on average. Moreover, East Germany is characterized by specific economic and institutional structures. Consequently, market and firm-specific characteristics may depend on the firm's location. The dummy **firm in East Germany** takes the value 'one' if a firm is located in the eastern part of Germany and it has the value 'zero' otherwise. 36% of all SME and 17% of all LE in the sample are located in East Germany.[24] Furthermore, the **asset-to-sales ratio**, which is a firm's asset divided by its total revenue, is included because it is an indicator of an industries' capital requirements (Rexhäuser & Rammer 2014); and therefore, connected to market-specific characteristics.[25] The average asset-to-sales ratio for SME is 38% and for LE 36%. Thus, capital intensity only slightly differs between both groups.

[24] The share of firms located in East Germany in the MIP sample is higher than in the total population of firms due to oversampling.

[25] Moreover, the asset-to-sales ratio is related to market entry barriers. Thus, it is linked to competition intensity (CP) as well.

4 Results

4.1 First step: EI in general

Table 4: First step: Environmental innovation in general.

Dependent variable	(1)	(2)	(3)	(4)
Return on sales in percent	ALL	SME	LE	ALL
Environmental innovation				
EI	0.715*	0.838*	0.0713	2.313**
	(0.355)	(0.419)	(0.668)	(0.708)
Interaction term with employees (in logs)				
EI & employees				-0.463**
				(0.178)
Control variables				
Pressure of increasing	-1.084**	-1.204**	-0.560	-1.014**
input prices	(0.361)	(0.450)	(0.551)	(0.361)
Market novelty	0.341	0.420	0.254	0.323
	(0.383)	(0.483)	(0.575)	(0.383)
Cost-saving innovation	1.046**	1.168*	0.527	1.087**
	(0.393)	(0.504)	(0.576)	(0.393)
Market share	2.172***	1.924**	3.119***	2.162***
	(0.552)	(0.667)	(0.938)	(0.551)
Competition pressure	-1.411***	-1.806***	-0.195	-1.420***
	(0.280)	(0.339)	(0.467)	(0.280)
Use of IPR	0.251	-0.209	1.297*	0.319
	(0.351)	(0.438)	(0.556)	(0.352)
Assets-to-sales ratio	-0.700***	-0.704**	-0.914*	-0.707***
	(0.201)	(0.238)	(0.366)	(0.200)
Employees (in logs)	-0.422***	-0.449**	-0.0126	-0.152
	(0.0947)	(0.147)	(0.227)	(0.140)
Firm in East Germany	-0.162	-0.326	0.748	-0.169
	(0.293)	(0.337)	(0.615)	(0.293)
Sector	X	X	X	X
Constant	8.940***	9.190***	5.883***	8.061***
	(0.815)	(1.043)	(1.536)	(0.880)
lnsigma	1.901***	1.953***	1.669***	1.900***
	(0.0163)	(0.0189)	(0.0327)	(0.0163)
N	2691	2093	598	2691

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Source: MIP 2015; own calculation.

Results of the first step are illustrated in Table 4. Estimating all firms jointly, ROS increases by 0.72 percentage points on average if a firm has an environmental innovation. Estimations (2) and (3) reveal, however, that a positive significant coefficient is only observable for SME (0.84 percentage points on average). Thus, the general positive effect observed in estimation (1) is rather driven by SME. Comparing the EI coefficients of estimations (2) and (3) by means of a Wald test shows that the difference between both groups is not significant (p-value = 0.33). Employing the interaction term (estimation (4)) confirms, however, that the positive effect of EI diminishes when the number of employees increases. Hence, the smaller the number of employees, the higher the benefits of environmental innovations. Besides, the estimated coefficient of the environmental innovation dummy (2.31 percentage points on average) becomes larger when applying the interaction term.

4.2 Second step: Different types of EI

In the second step, I analyze which EI types drive the general relationship between EI and ROS. Table 5 presents the results. According to estimation (1), none of the four innovation types is significant. Estimation (2) and (3) show how results change when SME and LE are estimated separately. Estimation (2) illustrates that for SME regulation-induced resource efficiency improvements are significantly related to an increase in ROS by 1.46 percentage points on average, whereas the three other types have no significant effects. Hence, profitability increases due to EI can only be supported for regulation & resource innovations. Estimation (3) reveals that the same EI type decreases profitability in LE by 1.81 percentage points on average. Other EI types do not show any significant effects for LE as well. A Wald test confirms that the effect of regulation-induced resource efficiency improvements significantly differs between both groups (p-value < 0.01). Table 2 illustrates that most firms have relative profits between -5% and 10%. Thus, effect differences at this size indicate a huge difference in profitability. Estimation (4) shows how the four innovation types interact with firm size. The coefficient of regulation-induced resource innovations increases up to 4.03 percent points on average. Hence, the positive correla-

Table 5: Second step: Different environmental innovation types.

Dependent variable	(1)	(2)	(3)	(4)
Return on sales in percent	ALL	SME	LE	ALL
Environmental innovation				
Regulation & resource	0.451	1.455*	-1.814*	4.027**
	(0.552)	(0.705)	(0.805)	(1.423)
Regulation & other	0.0822	0.0917	-0.562	-1.338
	(0.538)	(0.702)	(0.749)	(1.507)
Voluntary & resource	0.443	0.656	-0.790	1.977*
	(0.396)	(0.459)	(0.780)	(0.997)
Voluntary & other	-0.296	-0.433	0.338	-1.525
	(0.445)	(0.525)	(0.814)	(1.229)
Interaction terms with employees (in logs)				
Regulation & resource & employees				-0.887**
				(0.317)
Regulation & other & employees				0.335
				(0.333)
Voluntary & resource & employees				-0.438
				(0.254)
Voluntary & other & employees				0.320
				(0.302)
Control variables				
Pressure of increasing	-0.986*	-1.465**	0.566	-0.977*
input prices	(0.388)	(0.475)	(0.614)	(0.388)
Market novelty	0.375	0.461	0.384	0.370
	(0.384)	(0.482)	(0.574)	(0.383)
Cost-saving innovation	1.075**	1.125*	0.700	1.106**
	(0.394)	(0.505)	(0.571)	(0.394)
Market share	2.164***	1.913**	3.181***	2.126***
	(0.552)	(0.667)	(0.934)	(0.551)
Competition pressure	-1.410***	-1.829***	-0.116	-1.419***
	(0.280)	(0.339)	(0.464)	(0.280)
Use of IPR	0.252	-0.207	1.390*	0.310
	(0.352)	(0.438)	(0.555)	(0.353)
Assets-to-sales ratio	-0.707***	-0.727**	-0.967**	-0.704***
	(0.201)	(0.238)	(0.364)	(0.200)
Employees (in logs)	-0.412***	-0.443**	0.0173	-0.196
	(0.0946)	(0.147)	(0.225)	(0.128)
Firm in East Germany	-0.164	-0.311	0.657	-0.137
	(0.294)	(0.337)	(0.612)	(0.293)
Sector	X	X	X	X
Constant	9.109***	9.290***	6.276***	8.300***
	(0.810)	(1.038)	(1.511)	(0.868)
lnsigma	1.902***	1.952***	1.661***	1.899***
	(0.0163)	(0.0189)	(0.0327)	(0.0163)

N	2691	2093	598	2691

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Source: MIP 2015; own calculation.

tion between this innovation type and profits in firms with just a few employees is very high. Moreover, the coefficient of voluntary resource innovations becomes significant with a coefficient size of 1.98 percentage points. Looking at the interaction terms, regulation-induced resource innovations have a negative significant coefficient (-0.89). Consequently, the estimated coefficient of regulation-induced resource innovations decreases if the number of employees increases. The interaction term of voluntary resource innovations also shows a negative relationship, but the interaction term is only significant at a 10% level with a p-value of 0.09. Moreover, the main effect of employees in logs is not significant anymore, which indicates that the size coefficients especially in estimations (1) and (2) capture some size effects of environmental innovations.

In summary, the results show that environmental innovations in general are positively related to ROS. Splitting the observations between SME and LE indicates that the positive effect can only be attributed to SME, but this difference is not significant. Employing the interaction term, however, confirms that the positive effect of EI diminishes when the number of employees increases. Dividing environmental innovations by possible combinations of resource and regulation status indicates that differences are mainly driven by regulation-induced resource innovations. Including interaction terms in the second step shows that profitability increases with both types of resource innovations, but benefits are higher and significantly size-dependent when the innovation is regulation-driven. Besides, coefficients of other innovation types are not significant.

Table 6: MIP 2009.

Dependent variable	(1)	(2)	(3)	(4)	(5)
Return on sales in percent	ALL	SME	LE	ALL 2009	ALL 2015
Environmental innovation					
Regulation & resource	1.010*	1.154*	0.211	1.202	3.388*
	(0.456)	(0.522)	(0.901)	(1.239)	(1.332)
Regulation & other	-0.462	-0.766	0.858	-0.901	-1.359
	(0.444)	(0.507)	(0.875)	(1.208)	(1.431)
Voluntary & resource	0.588	0.592	0.516	0.765	1.610
	(0.302)	(0.331)	(0.749)	(0.795)	(0.945)
Voluntary& other	-0.208	-0.182	-0.216	-0.590	-1.293
	(0.322)	(0.355)	(0.772)	(0.857)	(1.168)
Interaction terms with employees (in logs)					
Regulation & resource & employees				-0.0513	-0.872**
				(0.291)	(0.301)
Regulation & other & employees				0.111	0.350
				(0.286)	(0.316)
Voluntary & resource & employees				-0.0503	-0.417
				(0.204)	(0.242)
Voluntary& other & employees				0.104	0.274
				(0.216)	(0.288)
Control variables					
Market novelty	0.266	-0.0503	1.203*	0.266	0.413
	(0.270)	(0.308)	(0.531)	(0.270)	(0.352)
Cost-saving innovation	0.365	0.565	-0.505	0.364	1.147**
	(0.275)	(0.318)	(0.511)	(0.275)	(0.373)
Market share	1.811***	1.736***	2.294**	1.812***	2.099***
	(0.402)	(0.450)	(0.889)	(0.402)	(0.525)
Competition pressure	-1.127***	-1.192***	-0.918*	-1.129***	-1.409***
	(0.212)	(0.237)	(0.459)	(0.212)	(0.266)
Assets-to-sales ratio	-0.498***	-0.457**	-1.078**	-0.499***	-0.595**
	(0.149)	(0.162)	(0.406)	(0.149)	(0.192)
Employees (in logs)	-0.426***	-0.543***	0.243	-0.448***	-0.264*
	(0.0729)	(0.104)	(0.244)	(0.102)	(0.122)
Firm in East Germany	-0.153	-0.225	0.304	-0.153	-0.248
	(0.229)	(0.247)	(0.649)	(0.229)	(0.279)
Constant	5.840***	6.494***	0.515	5.927***	8.270***
	(0.595)	(0.684)	(1.836)	(0.655)	(0.824)
lnsigma	1.789***	1.809***	1.636***	1.789***	1.841***
	(0.0145)	(0.0160)	(0.0345)	(0.0145)	(0.0174)
Observations	3612	3000	612	3612	2691

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Source: MIP 2015 & MIP 2009; own calculation.

5 Robustness Checks

5.1 Analyzing the MIP 2009

Contrary to the findings from Rexhäuser & Rammer (2014), the results of this work show that different EI types do not have a significant relation to ROS if size differences are not considered. However, coefficients of control variables used in both studies barely differ in their direction and significance level.

Different EI coefficients in both studies can occur for more than one reason. On the one hand, several differences in the empirical approach exist. First, environmental innovation dummies are defined differently: CO_2 emissions are not considered as resource efficiency improvements in the current study. But including CO_2 as a dimension of resource efficiency improvements—like Rexhäuser & Rammer (2014)—would also show insignificant results for the MIP 2015.[26] Secondly, the questionnaire changed between both waves. The response categories of the question 'whether an environmental innovation was implemented' changed from a four-point to a three-point Likert Scale. Thirdly, different control variables are used and the Herfindahl-Hirschman Index is excluded from the analysis because it does not show any effect in Rexhäuser & Rammer's (2014) paper.

On the other hand, relationships may have changed. To put it more precisely, the relationship between EI types and profitability may differ between both periods. This could be because returns of environmental innovations decreased especially for LE between the 2009 and the 2015 wave, but not for SME. This would indicate that size differences might vary over time.

To identify which issue causes the difference, the second step of the main analysis is repeated with MIP 2009 data. However, the same set of control variables is not available in both waves. Consequently, the analysis is only conducted with variables that are available for both periods.[27] The results are presented in Table 6. Estimation (1) shows

[26] The results are available from the author upon request.
[27] An estimation with same empirical approach as Rexhäuser & Rammer (2014) use was conducted as well. Except some minor differences it was possible to replicate their results.

that most EI coefficients still differ from Rexhäuser & Rammer (2014). Hence, differences in the empirical approach—i.e. a modified questionnaire and a different set of control variables—cause diverging results. But regulation-induced resource innovations still have a significant coefficient. Therefore, the relationship between regulation-induced resource innovations and profitability seems to be robust for the MIP 2009 because it is significant in both, my study as well as Rexhäuser & Rammer's (2014).

Even though the empirical approach causes diverging results, relationships still may have changed between both waves. Estimations (2) and (3) show results of both groups with MIP 2009 data and this study's empirical approach. The coefficient of regulation-induced resource improvements remains significant only for SME, but not for LE. However, the coefficients between both groups do not differ significantly according to a Wald test. This indicates that size differences have no strong impact in the MIP 2009. Hence, the analyzed time period may determine profitability gains of EI and respective size differences. In estimations (4) and (5) a regression with interaction terms is conducted with the same set of control variables for both waves. Estimation (4) presents results for the MIP 2009 and estimation (5) for the MIP 2015. In estimation (4) none of the coefficients is significant, but results of estimation (5) are similar to the main findings presented in Table 5 in section 4. Thus, for the MIP 2015 size differences are significant and robust, whereas for the MIP 2009 size differences cannot be observed. A Wald test indicates that the interaction term related to regulation-induced resource innovations significantly differs between both estimations (p-value = 0.04). Therefore, the size-dependency of EI changed between both waves.

As relationships changed, it is important to identify why and how firm size is related to it. If a firm starts to be environmentally active, it will probably first choose EI that reduce environmental pollution at low cost. However, the more environmental innovations a firm implements, the more difficult it might get to find another EI which is at least cost neutral. Hence, the development of new ways to reduce environmental pollution is likely to become more expensive over time, especially for developers of new processes. Since the start of a new federal government in Germany in 1998, formed by a coalition of the social democratic party and the green party, environmental policy has gained importance in Germany. A lot of the present environmental regulations were introduced in the early 2000s (Jänicke

Table 7: The influence of former EI.

Dependent variable Return on sales in percent	(1) ALL	(2) SME	(3) LE
Environmental innovation			
EI	1.530*	1.119	2.497*
	(0.650)	(0.762)	(1.214)
EI 2009	0.585	0.544	1.560
	(0.566)	(0.653)	(1.115)
Same EI in both waves	-0.481	0.127	-2.647*
	(0.732)	(0.877)	(1.280)
Control variables			
Pressure of increasing	-1.892**	-1.915*	-1.440
input prices	(0.626)	(0.764)	(0.953)
Market novelty	0.124	0.485	-0.842
	(0.658)	(0.807)	(1.031)
Cost-saving innovation	0.885	0.684	0.776
	(0.677)	(0.855)	(1.033)
Market share	2.546**	2.312*	3.393*
	(0.849)	(1.031)	(1.433)
Competition pressure	-1.333**	-1.810**	0.192
	(0.464)	(0.555)	(0.782)
Use of IPR	0.386	-1.061	3.464***
	(0.601)	(0.739)	(0.998)
Assets-to-sales ratio	-0.673*	-0.698*	-0.581
	(0.299)	(0.351)	(0.558)
Employees (in logs)	-0.433**	-0.355	-0.265
	(0.160)	(0.241)	(0.395)
Firm in East Germany	0.537	0.705	0.188
	(0.483)	(0.546)	(1.132)
Sector	X	X	X
Constant	9.326***	9.837***	5.795*
	(1.270)	(1.580)	(2.487)
lnsigma	1.890***	1.931***	1.598***
	(0.0272)	(0.0311)	(0.0564)
N	974	769	205

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Source: MIP 2015 & MIP 2009; own calculation.

2009). Therefore, between 2006 and 2008 (the reference period of the MIP 2009) it might have been easier for firms to find and introduce profitable resource-efficiency increasing EI than between 2012 and 2014 (the reference period of the MIP 2015). Increasing costs of EI are likely to hit SME later than LE or less because they are less often environmentally active and struggle more with resource efficiency improvements. Hence, the point where reducing environmental pollution harms SME's profitability might not have been reached during the reference period of the MIP 2015. Besides, a decreasing profitability of EI might also explain why the total amount of voluntary EI declined between both MIP waves (see Table 3).

To test this assumption, I analyze how former environmental innovations affect the relationship between environmental innovation and firm size. I combine both MIP waves to analyze the issue. My sample of firms that participated in both survey waves and provided full information on the model variables consists of 974 firms (769 SME and 205 LE). Moreover, this part of my analysis consists of three regressions. First, I test the influence of former EI on all firms jointly. Second, I split the sample into SME and LE.

I conduct my analysis based on equation (1), but adding two new variables. First, I add a dummy variable which is 'one' when an EI was implemented between 2006 and 2008 and 'zero' otherwise. Second, I add a dummy variable indicating whether an EI with the same dimensions of environmental benefits was introduced in both waves by the same firm. The dummy is 'one', for example, when a firm has introduced an EI which saves water in both periods. Unfortunately, no other MIP wave between 2009 and 2015 asked about environmental innovation. Therefore, some noise in the data exists due to the issue that I do not know whether a firm implemented an environmental innovation in the periods not covered by the waves 2009 and 2015 (i.e. in the years 2009 to 2011). Also, a selection bias is possible, as firms observed in the MIP 2009 and in the MIP 2015 again may have a higher profitability on average. This is because unprofitable firms might have left the market between both periods. Accordingly, the sample of firms that participated in both survey waves can significantly differ from the main sample (MIP 2015). Therefore, I test whether my subsample differs from it. A chi-squared test is applied for all discrete variables. Except for 'use of IPR' and 'pressure of increasing input prices', the null that both samples are drawn from the same distribution cannot be rejected. For continuous variables, I employ the nonparametric two-sample Kolmogorov–Smirnov (KS) test for equality of the overall cumulative distributions. The hypothesis of equal distributions for all continuous variables can also not be rejected here. Hence, I assume the subsample is representative for my entire sample.

The results are presented in Table 7. The first estimation shows that only EI exclusively implemented in the 2012-2014 period have a significant effect on profitability. In estimation (2), EI coefficients are not significant but point all into a positive direction. The sample is much smaller than in the main analysis and there is some multicollinearity between the coefficients, which explains why the coefficients of this estimation may not be significant anymore. However, estimation (3) now shows some positive effects for LE even though this sample is smaller: EI implemented between 2012 and 2014 have a significant positive coefficient of 2.5 percentage points on average. But if an EI with the same environmental benefits of an earlier EI was implemented, it reduces the relationship by 2.65 percentage points on average. Accordingly, both effects neutralize each other and a firm that implemented EI with the same dimension of environmental benefits in both periods does not profit from a potential positive relationship. So continuous environmental innovation is likely to decrease the positive relationship with profitability after a while in LE. This result confirms the assumption above. However, it needs further investigation to validate this hypothesis because there is some noise in the data and the sample is relatively small. Besides, environmental innovations that were introduced between 2006 and 2008 do not have a significant coefficient when no EI with the same dimension of environmental benefits was introduced between 2012 and 2014.

5.2 Taking account of past performence

A further analytical issue is potential endogeneity (Verbeek 2008). In other words, not only environmental innovations might influence firm profitability, but also firm profitability might influence the introduction of environmental innovations (King & Lenox 2001, Nelling & Webb 2009). Firms with higher profitability are likely to have slack resources. Therefore, they might be more willing to invest in sustainable technologies. Consequently, an endogeneity problem cannot be ruled out.[28] To take into account past performance, dummy variables for each ROS-interval from 2013 are generated and integrated into the

[28] Unfortunately, the interval structure of the ROS variable does not allow to take differences between two periods. Hence, it is not possible to calculate the change in profits resulting from the implementation of an EI.

model as explanatory variables.[29] Accordingly, nine dummies capture ROS in 2013. For example, one dummy takes the value 'one' if a firm reported a return between 2% and 4% in 2013 and 'zero' otherwise. The results from the second step are presented in Table 8. The integration of lagged ROS-dummies in the model increases the significance of most of the environmental innovation coefficients in the estimation. However, the size of the coefficients decreases. But comparing the coefficients with the results shown in Table 5 (main results) by means of a Wald test reveals no significant difference between the two estimates. Hence, this robustness check does not support the assumption of potential endogeneity.

6 Discussion & study limitations

Previous literature claims that — besides providing environmental benefits — regulation-driven environmental innovations increase firm profitability. Rexhäuser & Rammer (2014) state that this is only valid for innovations that improve resource efficiency. This study analyses if also firm size influences profitability gains of environmental innovations. My results show that significant size-dependent differences exist for the MIP 2015 wave. However, I do not find significant size-dependent differences for the MIP 2009 wave. A Wald test confirms that coefficients of interaction terms between regulation & resource innovations and firm size differ at a 5% level between both waves. Hence, effects of EI changed over time. The analysis of the influence of former EI provides an explanation why effects of EI vary. Table 7 shows that previous EI with the same environmental benefits influence the effect of present EI in LE negatively. This might be because profitable EI are more likely when a firm starts to substantially reduce the environmental impacts of its activities, which in Germany was often the case in the first half of the 2000s, following a change in federal environmental policy. But the more EI a firm has already implemented the more difficult it can get to find another profitable EI, which would explain negative effects in the MIP 2015 for LE as they implemented more EI in the past. However, there

[29] The dummies can be interpreted in the following way: Each ROS-interval dummy has a different likelihood that the ROS in the next period (2014) will be high. A high estimated coefficient of a profitability dummy indicates a high likelihood that the profitability in the next period will be on a high level.

Table 8: Taking account of past performence.

Dependent variable	(1)	(2)	(3)	(4)
Return on sales in percent	ALL	SME	LE	ALL
Environmental innovation				
Regulation & resource	0.401	1.070**	-1.110**	2.235**
	(0.296)	(0.382)	(0.407)	(0.773)
Regulation & other	-0.0188	-0.167	0.164	-0.371
	(0.288)	(0.380)	(0.378)	(0.818)
Voluntary & resource	0.297	0.457	-0.388	1.110*
	(0.215)	(0.253)	(0.393)	(0.550)
Voluntary & other	-0.194	-0.297	0.0369	-0.333
	(0.239)	(0.285)	(0.411)	(0.668)
Interaction terms with employees (in logs)				
Regulation & resource & employees				-0.459**
				(0.172)
Regulation & other & employees				0.0818
				(0.180)
Voluntary & resource & employees				-0.232
				(0.139)
Voluntary & other & employees				0.0340
				(0.164)
Control variables				
Pressure of increasing	-0.133	-0.289	0.338	-0.130
input prices	(0.209)	(0.259)	(0.310)	(0.209)
Market novelty	0.0965	0.0919	0.0135	0.0953
	(0.207)	(0.263)	(0.292)	(0.207)
Cost-saving innovation	0.283	0.321	0.127	0.309
	(0.214)	(0.277)	(0.292)	(0.214)
Market share	0.474	0.831*	-0.425	0.455
	(0.301)	(0.369)	(0.481)	(0.300)
Competition pressure	-0.460**	-0.487**	-0.246	-0.473**
	(0.152)	(0.187)	(0.233)	(0.152)
Use of IPR	0.0327	-0.0631	0.391	0.0783
	(0.189)	(0.238)	(0.283)	(0.190)
Assets-to-sales ratio	-0.222*	-0.278*	-0.156	-0.223*
	(0.109)	(0.131)	(0.188)	(0.109)
Employees (in logs)	-0.0263	-0.00337	-0.0706	0.125
	(0.0516)	(0.0813)	(0.113)	(0.0701)
Firm in East Germany	0.125	0.147	0.292	0.136
	(0.159)	(0.185)	(0.309)	(0.159)
Lagged return-on-sales dummies[d]				

-5% to < 2%	4.489***	4.672***	4.204***	4.460***
	(0.448)	(0.544)	(0.711)	(0.447)
-2% to < 0%	5.609***	5.711***	5.463***	5.601***
	(0.404)	(0.482)	(0.674)	(0.403)
0% to < 2%	6.570***	6.555***	6.481***	6.529***
	(0.334)	(0.404)	(0.531)	(0.333)
2% to < 4%	8.318***	8.404***	8.008***	8.276***
	(0.334)	(0.405)	(0.528)	(0.333)
4% to < 7%	10.23***	10.22***	10.32***	10.18***
	(0.327)	(0.395)	(0.521)	(0.326)
7% to < 10%	13.21***	13.12***	13.20***	13.14***
	(0.344)	(0.413)	(0.573)	(0.343)
10% to < 15%	16.42***	16.54***	15.99***	16.36***
	(0.371)	(0.439)	(0.652)	(0.370)
15% and more	22.73***	23.32***	20.63***	22.69***
	(0.418)	(0.502)	(0.700)	(0.418)
ROS in 2013 missing	10.22***	13.61***	3.094	10.26***
	(2.086)	(2.764)	(2.690)	(2.082)
Sector	X	X	X	X
Constant	-4.863***	-4.843***	-4.404***	-5.377***
	(0.524)	(0.666)	(0.882)	(0.548)
lnsigma	1.234***	1.295***	0.915***	1.231***
	(0.0164)	(0.0189)	(0.0341)	(0.0164)
N	2676	2081	595	2676

a Standard errors in parentheses

b * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

c Source: MIP 2015; own calculation.

d Baseline interval: return on sales below -5%

is some noise in the data set, so this argument needs further investigation. Also, another argument why effects differ is that the effect of regulation on environmental innovation depends on policy—and policy can vary over time. Hence, effects may diverge for more than one reason and the first limitation of this study is that I cannot clearly identify the cause.

Another limitation of my study is that I cannot identify a single cause why effects diverge between SME and LE in the MIP 2015. According to the literature, possible reasons for diverging effects between SME and LE include (1.) general differences regarding innovation patterns, (2.) legislative asymmetries and (3.) differences regarding the influence of regulation on resource efficiency improvements. In theory, general differences can affect all innovation types. Additionally, regulation may cause legislative asymmetries and differences related to resource efficiency improvements like benefits from information gains.

Theoretically, diverging effects of regulation & resource EI might be caused by all three factors. As a consequence, it cannot be clearly identified which factor causes diverging effects. But Table 5 shows that size differences of regulation-induced & resource innovations are larger than those of voluntary & resource ones, which are only driven by general differences. Hence, regulation either via channel (2.) or (3.) could be one factor influencing size differences of environmental innovation. This argument is also supported by the descriptive statistics. Table 3 reveals that 43% of all LE and only 21% of all SME implemented a regulation-induced innovation between 2012 and 2014. In contrast, the share of firms that implemented a voluntary innovation does not notably differ in both groups. This indicates that environmental action is more often enforced by law in LE. Hence, especially enforcement asymmetries (as a part of legislative asymmetries) could also explain why effects differ. However, it is not possible to identify enforcement asymmetries based on the MIP 2015 because the influence of regulation is only observed for firms that introduced an environmental innovation (see section 3.3.2 for a discussion of this issue). Therefore, this study cannot certainly identify which difference causes diverging effects between SME and LE and an in-depth investigation, which provides a deeper understanding, would be appropriate to complement my results.

Moreover, it has to be discussed to what extent my results provide a deeper understanding about the validity of the Porter hypothesis. The MIP only covers the effect of regulation when an environmental innovation was introduced. As a consequence, abatements costs as well as size differences of regulated firms that did not implement an environmental innovation remain unobserved in this study. Thus, the overall influence of environmental regulation on firm profitability is not fully analyzed. Therefore, Rexhäuser & Rammer (2014) state that the applied estimation approach does not allow to confirm the Porter hypothesis' strong version. But, one could argue that my results for the MIP 2015 disprove the Porter hypothesis' strong version for LE in this period because no positive effect of EI is found for this group: Abatement costs unambiguously affect firm profitability negatively and there is no innovation type which could cause an overall positive effect of regulation on firm profitability. However, this argument does not consider period-specific effects. The MIP 2009 shows, different effects may exist in other periods. Hence, further research is needed that captures the combined net effect of pollution abatement costs and environmental innovations over several periods with respect to firm size. Respective results would provide a deeper understanding of the firm size dependency of environmental innovation and allow making conclusions about the Porter hypothesis' strong version.

7 Conclusion

Porter (1991) and Porter & van der Linde (1995) state that regulation-induced environmental innovations can increase firm profitability. Rexhäuser & Rammer (2014) show with the MIP 2009 for the German economy that only resource efficiency-improving innovations increase, while other environmental innovations decrease profitability regardless of whether regulation-induced or not. As environmental innovation patterns differ between SME and LE (Klewitz & Hansen 2014), I additionally claim that firm size influences profitability gains of EI as well. This is because general differences between SME and LE, legislative asymmetries as well as differences regarding the influence of regulation on resource efficiency improvements may cause diverging effects.

To test my assumption, I use data from two waves of the *Mannheim Innovation Panel* (MIP) consisting in total of 6,303 German firms. The MIP 2015 is used for the main analysis and the MIP 2009 for robustness checks. My results confirm size differences for the MIP 2015 wave, which are mainly driven by regulation-induced resource innovations. Such environmental innovations are significantly related to an increase in profits of SME, but to a decrease in profits in LE. However, I do not find significant size-dependent difference in the MIP 2009 wave. That's why I conclude that the role of firm size differences depends on the specific time period. One explanation for this result is that profitable EI might be more likely when a firm starts to substantially reduce the environmental impacts of its activities, but after a while it is likely that it gets more difficult to find further profitable EI. As LE implemented more EI in the past already, this issue is more relevant for them and explains size differences in the MIP 2015 wave. However, size differences in the MIP 2009 wave are not observable because most firms just might started to reduce environmental externalities, due to a change in federal policy.

As size differences vary between the observed time periods, it is difficult to define concrete policy implications. But I recommend that environmental law should take into account different innovation patterns between larger and smaller firms and potential legislative asymmetries. Additionally, policies that provide information about potential technological improvements have the chance to increase resource efficiency and especially support smaller firms.

Due to data restrictions, this study represents only a first approach to the analysis of firm size differences related to the Porter hypothesis. Further studies should observe the role of regulation as well as pollution abatement costs for all firms, not solely for those that implemented an environmental innovation. Additionally, an in-depth (qualitative) investigation analyzing which differences between SME and LE are the most influential for diverging effects of regulation-induced resource efficieny improvements would complement my results. Moreover, the influence of time and regulation regime should be analyzed more deeply. For example, investigating if and how the rate of environmental innovations induced by a specific policy varies over time and whether respective effects differ for SME and LE could provide a deeper insight.

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8 Appendix

Table 9: Observations with an ambiguous assignment of regulation status (MIP 2015).

Type of environmental innovation	Group	Not influenced by regulation	Influenced by regulation	Total
Only resource	ALL	353	175	528
	SME	294	118	412
	LE	59	57	116
Only other	ALL	85	45	130
	SME	72	27	99
	LE	13	18	31
Both	ALL	323	445	768
	SME	235	270	505
	LE	88	175	263
No EI	ALL			1265
	SME	[-]	[-]	1077
	LE			188
Total	ALL			2691
	SME	[-]	[-]	2093
	LE			598

Source: MIP 2015; own calculation.

Table 10: Types of environmental innovation by sector (MIP 2015).

		Regulation & resource	Regulation & other	Voluntary & resource	Voluntary & other	SME	Pressure of increasing input prices
Energy, mining and oil refineries (5-9, 35)	106	0.28	0.21	0.13	0.08	0.62	0.32
Food, beverages, and tobacco products (10-12)	120	0.31	0.23	0.38	0.25	0.77	0.49
Textiles, wearing apparel, and leather products (13-15)	102	0.23	0.18	0.28	0.13	0.87	0.35
Wood and paper products (16-18)	93	0.35	0.25	0.23	0.16	0.80	0.51
Chemical and pharmaceutical products (20-21)	94	0.36	0.30	0.27	0.20	0.66	0.37
Rubber and plastic products (22)	82	0.33	0.21	0.26	0.18	0.72	0.41
Other non-metallic mineral products (23)	75	0.39	0.33	0.32	0.21	0.79	0.52
Basic metals and metal products (24-25)	204	0.27	0.22	0.29	0.18	0.76	0.41
Electronic and electrical products (26-27)	189	0.30	0.26	0.29	0.22	0.77	0.36
Machinery (28)	143	0.36	0.31	0.31	0.20	0.55	0.39
Vehicles and transport equipment (29-30)	67	0.46	0.42	0.21	0.19	0.58	0.45
Furniture and other manufacturing (31-33)	155	0.19	0.14	0.28	0.15	0.87	0.28
Water supply and waste management (36-39)	140	0.26	0.24	0.24	0.17	0.80	0.33
Wholesale (46)	113	0.16	0.12	0.21	0.10	0.74	0.25
Transportation and post (49-53)	199	0.27	0.24	0.18	0.10	0.76	0.31
Media services, telecommunication (58-61)	129	0.10	0.07	0.31	0.18	0.87	0.22
Information and communication services (62-63)	109	0.10	0.04	0.28	0.12	0.89	0.15
Financial and insurance activities (64-66)	93	0.10	0.06	0.18	0.09	0.67	0.12
Technical services and and scientific research (71-72)	157	0.15	0.10	0.22	0.14	0.92	0.20
Consultancy and advertisement (69, 70.2, 73-74)	179	0.02	0.02	0.21	0.03	0.97	0.08
Business services (78-82)	142	0.10	0.07	0.22	0.15	0.73	0.13
Total	2691	0.23	0.18	0.25	0.15	0.78	0.31

Source: MIP 2015; own calculation.

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