How do different innovation forms mediate the relationship between environmental regulation and performance?

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Abstract: The Porter Hypothesis (PH) challenges the traditional view on the relationship between environmental regulation and performance by arguing that different innovation forms stimulated by regulations can improve firm performance. However, little of the extant literature discusses how different innovation forms mediate the relationship involved in the Porter Hypothesis. Therefore, in this study, we attempt to provide a model to compare the mediation roles of process innovation and product innovation in the PH, using data from 35 industrial sectors in China from 2001 to 2010. Empirical results indicate that while both process innovation and product innovation mediate the causal link between environmental regulation and performance, product innovation has a slightly stronger mediation effect than process innovation.

Keywords: Environmental regulation; Innovation forms; Process innovation; Product innovation; Performance; Mediation model

1. Introduction

In the past several decades, the Porter Hypothesis has attracted much attention from academics and policy makers. In the early 1990s, Michael Porter and his colleague Van der Linde challenged the conventional wisdom that regulations increase firms' environmental compliance costs, hence limiting their investment in other activities, ultimately leading to low performance (Porter 1991; Porter and Van der Linde 1995). They provided a contrary

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view by stating that more severe but well-designed environmental regulations may lead to greater productivity and higher performance by triggering innovations. Their view on this causal chain between environmental regulation, innovation, and performance is well known as the Porter Hypothesis (PH). The PH provides us with a fresh positive perspective on the relationship between environmental regulations and economic development, and it has stimulated many research efforts among scholars and policymakers (Klassen and Whybark 2000; Triebswetter and Wackerbauer 2008). More and more relevant literature has tested the relationships between environmental regulation, innovation, and firm performance (Palmer and Portney 1995; Thomas 2009; Wan Alwi, Klemeš, and Varbanov 2016).

According to the PH, innovation plays a mediating role in the relationships between environmental regulation, innovation, and firm performance. Through innovation stimulated by environmental regulation, firms have lower energy consumption or higher quality products, the benefits of which exceed the cost of compliance (defined by Porter as innovation offsets), finally leading to better performance. From Porter's point of view, innovation occurs in two forms when firms face environmental regulation (Porter 1991; Porter and Van der Linde 1995). The first innovation form occurs in the product process. Firms curb pollution emissions through technical transformation in their production line, or just in the end-of-pipe. The second innovation form aims at reforming the products themselves. Through new designs, firms produce less-polluting and better-performing new products. According to the literature in the innovation management field, these two forms mentioned by Porter are consistent with the concepts of process innovation and product innovation (Adner and Levinthal 2001; Fondas 1994; Danneels 2002; Li and Atuahene-Gima 2001). Porter further demonstrated that the two different innovation forms could lead to different innovation offsets, which are the reasons why environmental regulation can actually improve firm performance. Process innovation results in process offsets because it can increase the utilization rate of resources, to cover parts of costs. Product innovation is considered to be the main factor producing product offsets, because this innovation form aims at designing and producing green and popular products. Porter thinks in theory that different forms of innovation may play different roles and they might derive from different innovation strategies and investments (López-Gamero, Molina-Azorín, and Claver-Cortés

2010; Porter and Van der Linde 1995).

However, few empirical studies focusing on the different innovation forms in the PH have been conducted. In the extensive body of literature discussing the PH in theory and practice, scholars have simply used different variables to measure innovation, such as R&D expenditures and patent applications, lacking a deeper understanding of the different innovation forms in the PH (Jaffe and Palmer 1997; Artz et al. 2010). In reality, both process innovation and product innovation often exist simultaneously (López-Gamero, Molina-Azorín, and Claver-Cortés 2010). They are two different steps taken by firms to respond to external stress from environmental regulation. Therefore, simply using R&D expenditures as innovation inputs or patent numbers as innovation outputs leads to a relatively vague understanding of innovation forms (Yang, Tseng, and Chen 2012; Rexhäuser and Rammer 2014). In this way, it is difficult to distinguish between the two innovation forms identified by the PH.

Therefore, this study sets out to examine the role of innovation in the PH by taking into account innovation forms, in the terms of process innovation and product innovation. Following Porter's original idea, we consider innovation as playing a mediating role in the relationship between environmental regulation and performance. In the PH, a clear causal link is revealed from environmental regulation to innovation and then from innovation to performance. Such a causal relationship just is in line with the mediation model, in which innovation is a mediator between environmental regulation and performance. In this paper, two different innovation forms are involved, so a multiple mediation model is chosen for a comprehensive testing model. In the prior literature, most researchers used industry-level data to examine the PH, because data from firms is relatively difficult to obtain. Likewise, considering the data availability, an industry-level panel data for 35 Chinese industrial sectors from 2001 to 2010 is employed in our study.

The contributions of this paper to the literature are threefold. First, to strengthen our understanding on the innovation forms of the PH, we distinguish innovation forms into process innovation and product innovation, and compare their differential mediation effects in the relationship between environmental regulation and performance. Despite much research on the PH, there is a lack of understanding regarding the different innovation forms. Therefore, our research can provide a newer and more in-depth empirical analysis from an innovation management perspective to discuss the environmental regulation problems.

Second, a comprehensive framework is adopted in this paper to empirically test the PH. Scholars have divided the PH into a weak version, which focuses on the relationship between regulation and innovation, and a strong version, testing that innovation induced by environmental regulation contributes to higher firm performance (Jaffe and Palmer 1997; Ambec et al. 2013). In the earlier studies, we can find some relevant empirical literature only on the weak PH, or only on the strong PH. Recently, a handful of papers have started to test both the weak and the strong version of the PH. In fact, the essence of the PH is a causality between environmental regulation, innovation, and performance, in which innovation plays a role of mediation. Therefore, we need a complete framework to involve all elements, rather than the weak version or the strong version separately.

Third, this empirical study enriches the extant literature on the PH from the perspective of an emerging economy, China. As one of the biggest developing countries, China's serious environmental problems have drawn worldwide attention. As a result, we urgently need to find a solution to resolve the stress between environmental regulation and business performance. Our research thus can provide the Chinese government and policy makers in other developing countries with information when they face the same problems.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature and provides a conceptual model. Section 3 introduces the data and methods used in this study. Section 4 presents empirical results. Finally, in section 5, we provide an in-depth discussion, including some theoretical and managerial implications. The limitations of this study will also be addressed to guide future research.

2. Literature review and conceptual framework

Environmental regulation has been a controversial and unavoidable issue for a long time, due to the dilemma between economic development and environment constraints. The conventional viewpoint is that environmental regulations, such as taxes on environmental production, and expenditures on pollution abatement, reduce business performance because they increase firms' cost burdens, and deter firms from some profitable investments (Gray 1987; Kalt 1985). This view has been challenged by a number of researchers, in which the Porter Hypothesis is notably proposed by Porter and Van der Linde. The PH is not the first theory to go against the conventional wisdom on innovation (Hicks 1963), but its systematic explanation about the causal relationship between environmental regulation, innovation, and performance rekindled the debate on environmental regulations. Using case analysis, Porter and Van der Linde explain that environmental pollution itself is a waste of resources and causes low productivity for firms, so if the regulations are well designed, they can trigger innovation. Through innovation, firms will achieve more efficient resource utilization and produce popular green products, which may offset the costs of regulatory compliance and enhance performance (Ambec et al. 2013; Porter 1991; Porter and Van der Linde 1995). Actually, the PH proposes a logical chain from environmental regulation to innovation, and then to performance.

From the perspective of the PH, innovation stands in the center of the causal chain. As Porter stresses, the positive effect of environmental regulation on firm performance contributes to innovation offsets. Further, he claims that innovation offsets can be broadly divided into process offsets and product offsets, because innovation is not only technology changes but also new product design. Different innovation forms lead to different innovation offsets. Process innovation may bring process offsets because when firms use new technology to solve pollution, they can also improve resource utilization and reduce energy consumption. These offsets result in cost reduction, as they are helpful for firm performance. Product offsets occur because product innovation yields better-performing green products, which are beneficial for firms in generating sales. In fact, Porter's understanding about innovation forms conforms to studies on innovation management (Rosenkranz 2003; Becker and Egger 2013). In the field of innovation research, process innovation and product innovation are two general classifications that distinguish and compare different kinds of innovation activities, and especially their influences on firm performance (Martínez-Ros and Labeaga 2009). Thus, according to the original arguments and the evidence from innovation literature, the framework in Figure 1 can integrate all of the elements and their links involved in the PH.

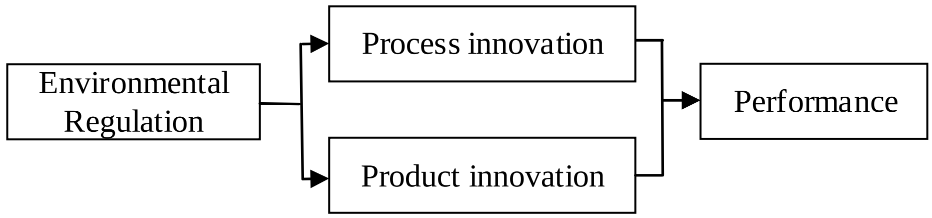

Figure 1.

The conceptual framework of the PH

Although a growing group of studies has tested the PH using empirical methods, they do not distinguish between the two innovation forms. Jaffe and Palmer first used R&D expenditures and patent applications to measure innovation in their work examining the PH (Jaffe and Palmer 1997). Based on industrial level panel data, they found a significant positive effect of environmental regulation on R&D expenditures, but an insignificant effect on patent applications. Following that, many empirical studies in environmental literature have provided much evidence to test the PH using diverse data, in which R&D investments and patent numbers have become two popular measurements for innovation (Lanoie et al. 2010; Broberg et al. 2013; Asano and Matsushima 2014; Rubashkina, Galeotti, and Verdolini 2015). Such a general input or output indicator of innovation cannot distinguish whether these innovation forms improve the technology in the process or design a new product. Actually, in the innovation literature, many studies have discussed process innovation and product innovation (Adner and Levinthal 2001; Becker and Egger 2013; Boone 2000). Innovation researchers argue that different innovation forms will be used in various firms and then produce performance in two ways. The former concentrates on cost cutting and productivity increases using technology evolution, while the latter aims at sales increases by improving a product itself (Martínez-Ros and Labeaga 2009). However, there is a lack of in-depth understanding on these two innovation forms in the environmental research field, and what roles different innovation forms play in the relationships of the PH.

Meanwhile, regarding the model to test the PH, scholars either use weak or strong means, neglecting a comprehensive framework. To test the relationships of the PH, researchers have generally divided it into the weak version and the strong version. Some research only investigates the weak PH, a relationship between environmental regulation and innovation (Brunnermeier and Cohen 2003; Johnstone, Haščič, and Popp 2008; Kneller and Manderson 2012; Yabar, Uwasu, and Hara 2013). Although most of them find regulation has a positive effect on innovation, it is uncertain whether this innovation can promote firm performance (Ambec et al. 2013). Another branch of research tests the strong PH, focusing on the link between environmental regulation and performance (Lanoie, Patry, and Lajeunesse 2008; Horvathova 2012; Broberg et al. 2013). Only a small number of studies examine the relationships between regulation, innovation, and performance simultaneously (Lanoie et al. 2010; Rubashkina, Galeotti, and Verdolini 2015; Ramanathan et al. 2016). Even these studies simply run regression tests on the relationships between regulation and innovation, and between innovation and performance.

According to the framework of the PH (see Figure 1), the causality chain among regulation, innovation forms, and performance is a typical mediation model. Mediation is defined as a process where "influences of an antecedent are transmitted to a consequence through an intervening variable" (James and Brett 1984). In other words, the independent variable leads to the mediator, and the mediator leads to the outcome (Jr and Sweeney 1991). The link between environmental regulation and innovation and performance is a mediation process where environmental regulation causes innovation, and innovation causes performance. Thus, a mediating model provides us with a ready-made method to examine the relationships in the PH, rather than a fragmented view that splits the coherent PH. In this study, we will follow the logic of the PH, using a mediation model to explore how process innovation and product innovation mediate the relationship between environmental regulation and performance.

3. Data and methodology

3.1 Data and sample

It is a significant challenge to acquire valid data to test the PH with. Inevitably, most researchers have gotten stuck when attempting to collect data at the firm level. Instead, they generally use industrial data to examine the PH. In this study, following the traditional method, we also use data from the industry level to test the PH. Dynamic panel data were collected from 35 industrial sectors of China for the period 2001–2010. The data are from annual yearbooks, released by the National Bureau of Statistics, including the China Statistical Yearbook, the China Statistical Yearbook on Science and Technology, and the China Statistical Yearbook on Environment. Notably, up to and including 2010, the investigation data released by the National Bureau of Statistics covered large and medium industrial enterprises with annual revenue from principal business of over 10 million yuan. Since 2011, the data have covered industrial enterprises above a designated size, with annual revenue from principal business of over 5 million yuan, so the sample is not unified between the two periods. In addition, there are many missing indicators for statistical data from 2000 and earlier. Therefore, to adopt uniform data, and considering the availability of the data, we selected balanced panel data from 35 industrial sectors spanning ten years, from 2001 to 2010.

3.2 Variable measurements

3.2.1 Environmental regulation

In terms of selecting a proxy for environmental regulation, we used data on the operating cost of facilities for the treatment of waste gas and water. In prior studies, scholars employed multiple methods and proxy variables to measure the level of governmental environmental regulations (Brunel and Levinson 2013; Calel and Dechezlepretre 2016; Nesta, Vona, and Nicolli 2014), such as pollution abatement costs and expenditures (*PACE*), as well as the number of environmental laws enacted by the government and the pollution emission concentration. However, most researchers use the costs of or expenditures on pollution abatement. The reason for this is that firms will spend more money on environmental pollution treatment when faced with strict environmental regulations. There is a significant positive association between the two variables, so PACE becomes a feasible proxy for environmental regulations (Rubashkina, Galeotti, and Verdolini 2015). In line with most of the literature, we also employ PACE as a proxy for environmental regulations (*ER*) in our research. We collect the cost of facilities for the treatment of waste gas and water as PACE, excluding solids because they are not included in the China Statistical Yearbook on Environment. To eliminate the dimension and effects of different variances, this variable is operationalized as the natural logarithm of the cost of facilities for the treatment of waste gas and water (Yang, Tseng, and Chen 2012).

3.2.2 Innovation forms

In this study, innovation is divided into two different forms, process innovation and product innovation. Taking the literature from the innovation management field as a reference (Becker and Egger 2013; Martínez-Ros and Labeaga 2009), we employ expenditures for technical renovation to replace process innovation, and spending for new products as the proxy variable of product innovation. These data are taken from the China Statistical Yearbook on Science and Technology. A natural logarithm is adopted to eliminate the dimensions and effects of different variances.

3.2.3 Performance

In line with the existing literature, business performance is operationalized in terms of an accounting indicator. Accounting measures, such as return on sales and return on investment, are frequently used to measure a firm's economic performance (Khanna and Damon 1999). In this paper, we use net profit margin measured by the percentage of net profit in total sales as a proxy variable for business performance. A high profit margin indicates a high margin of safety. To some degree, industrial sectors with more robust profitability often show higher performance.

3.2.4 Control variables

Some variables at the level of industry are controlled to address the unobserved heterogeneity. First, we include the natural logarithm of total employed persons as a scaling factor (*Size*) because larger industries are likely to have a higher level of PACE (Rubashkina, Galeotti, and Verdolini 2015), and industries of different scales differ according to their innovation strategies (Brío and Junquera 2003). Second, we control the financial *leverage* using the current ratio because a firm's leverage ratio will influence its innovation investment and financial performance (Chen and Zhao 2006). Third, the social innovation situation is important in this research. China has been promoting an "indigenous innovation" policy since 2006, which promotes the increasing of firms' innovation inputs (Fu, Pietrobelli, and Soete 2011). We control for this by using a dummy variable—*Macropolicy*. For years before 2007, we make this variable equal to 0, and 1 otherwise.

3.3 Methods

This study relies on hierarchical linear models (HLMs) to test mediated effects in multiple mediation models with more than one proposed mediator variable (Preacher and

Hayes 2008; Zhang, Zyphur, and Preacher 2009). Investigating using a multiple mediation model involves three steps: (1) calculating the total mediating effect, and deciding whether the set of mediators transmits the effect of X to Y; (2) testing individual mediators in the context of a multiple mediator model; (3) contrasting the mediating effects of individual mediators. In the first and second steps, we adopt a conventional approach by estimating the parameters of a causal stepwise chain (Baron and Kenny 1986); the Sobel test and Freedman test are also applied as a supplement (Freedman and Schatzkin 1992; Sobel 1982). In the third step, we use MacKinnon’s method (2002) to test the differential mediating effects of a single pairwise contrast. Four models are involved in this study, in which the dependent variable of the first and the fourth models is performance measured by the net profit margin, while in the second and third it is innovation measured by a natural logarithm greater than zero. Therefore, we choose a panel Tobit model as our statistical model (Nassimbeni 2001). In this study, the tests indicate that random models are appropriate. Estimation results for each model were computed using Stata 13.

4. Empirical results

4.1 Main analysis

Table 1 presents descriptive statistics and a correlation matrix for all variables used in this study. The correlations between most variables are not high, except for the correlation between Size and product innovation (0.789). This value is high enough to suggest a multicollinearity problem. However, a robust test indicates that the highest variance inflation factor is 2.61, lower than the critical threshold value of 10, which suggests that the empirical results are not influenced by this cross-correlation (Chatterjee 1991).

Table 1.
Descriptive statistics and correlations

Variables	Mean	S.D.	Min	Max	1	2	3	4	5	6	7
1.Performance	7.482	6.740	-5.533	47.36	1						
2.ER	11.029	1.698	6.924	15.332	0.055	1					
3.Process innovation	12.209	1.804	5.124	16.268	-0.001	0.534	1				
4.Product innovation	11.641	2.060	5.407	15.784	-0.082	0.479	0.565	1			
5.Size	13.469	1.007	10.863	15.618	-0.051	0.590	0.574	0.789	1		
6.Leverage	1.083	0.271	0.445	2.949	0.171	-0.373	-0.022	0.063	-0.160	1	
7.Macropolicy	0.4	0.491	0	1	0.147	0.226	-0.028	0.368	0.186	0.174	1

Table 2 presents the statistical results, including OLS models (for model 1 and model 4) and panel Tobit models (for model 2 and model 3). To avoid the endogeneity problem, an environmental regulation variable and two innovation variables are specified in 1-year lagged forms (Yang, Tseng, and Chen 2012). All models are reported by using the Wald chi-squared test. To test the mediation effects of process innovation and product innovation on the relationship between environmental regulation and performance, we first test the relationship between environmental regulation and performance in model 1. ER shows a significant and positive relationship with performance ($\beta=0.612$, $p<0.1$). Next, we regress the dependent variable (ER) on the two mediators (Process innovation and Product innovation) in model 2 and model 3. The coefficients are positive and significant (for Process innovation, $\beta=0.436$, $p<0.01$; for Product innovation, $\beta=0.258$, $p<0.01$). Finally, we insert ER and two mediators into the full model, model 4. We find that only Product innovation still shows a positive and significant effect, while the coefficients of ER and Process innovation are insignificant. According to Baron and Kenny's research, when one of the coefficients is insignificant, changes in coefficients alone cannot indicate a mediation effect. Therefore, we added two alternative tests as a supplement, and compared the mediation effects of two innovation forms. The first is the Sobel test, which is used as a product of coefficient approach (Sobel 1982). The other is the Freedman test, which is used as a difference in coefficients approach (Freedman and Schatzkin 1992). According to the Sobel test and the Freedman test, if the Z-value or the T-value is significant, then the mediation effect is significant. These two test results are reported in Table 3, supporting the mediation effects of process innovation and product innovation on the relationship between environmental regulation and performance. Figure 2 presents the model parameters.

Table 2.
Regression results (all industries)

Variables	Model (1) Performance	Model (2) Process Innovation	Model (3) Product Innovation	Model (4) Performance
ER_{t-1}	0.612*	0.436***	0.258***	0.460
	(0.338)	(0.086)	(0.067)	(0.347)
Process $innovation_{t-1}$				0.109

				(0.122)
Product innovation$_{t-1}$				0.541*
				(0.293)
Size	0.272	0.702***	1.167***	−0.421
	(0.611)	(0.135)	(0.119)	(0.701)
Leverage	6.630***	1.574***	0.337	6.389***
	(1.114)	(0.388)	(0.221)	(1.120)
Macropolicy	0.552	−0.910***	0.788***	0.138
	(0.409)	(0.161)	(0.080)	(0.486)
Constant	−10.117	0.702***	1.167***	−6.207
	(7.684)	(0.135)	(0.119)	(7.973)
Wald chi^2	75.31	109.9	803.6	80.25
Observations	315	315	315	315
Number of industry	35	35	35	35

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 3.
Results of Sobel test and Freedman test (all industries)

Mediators	c	δ_c	c'	$\delta_{c'}$	a	δ_a	b	δ_b	r_{xm}	Effect ratio	Sobel test(Z)	Freedman test(t_{N-2})
Process innovation	0.612	0.338	0.46	0.347	0.436	0.086	0.109	0.122	0.508	0.254	0.880*	4.662***
Product innovation	0.612	0.338	0.46	0.347	0.258	0.067	0.541	0.293	0.473	0.746	1.665**	5.432***

c is the direct effect of ER on Performance without mediators, while c' is the direct effect after adding mediators
r_{xm} is the covariance between ER and Innovation
Effect ratio=$a_i*b_i/(a_1*b_1+a_2*b_2)$
$Z=a*b/sqrt(a^2\delta_b^2 + b^2\delta_a^2)$, $t_{N-2}=(c- c')/(sqrt(\delta_c^2+\delta_{c'}^2-2*\delta_c*\delta_{c'}*sqrt(1- r_{xm}^2))$
*** p<0.01, ** p<0.05, * p<0.1

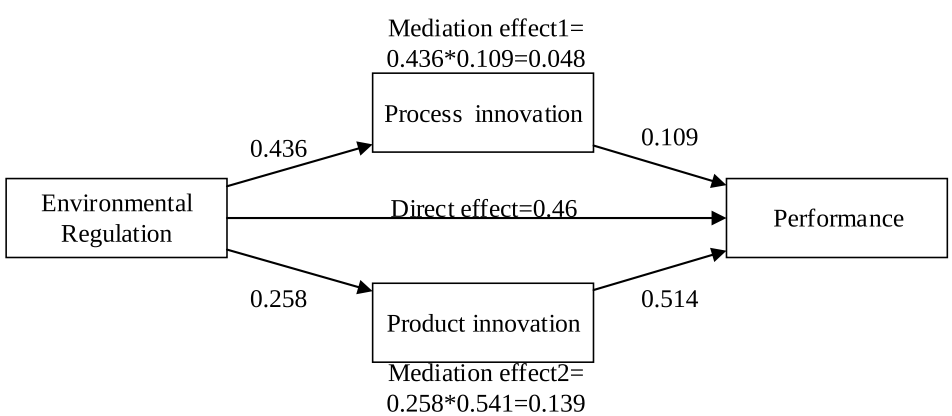

Figure 2.

Model parameters (all industries).

The above results suggest that the effect of environmental regulation on performance is carried out through two parallel mediating paths: process innovation and product innovation. In that case, a comparison should be done to reveal whether these two mediation effects are different, and if so, which mediation effect is stronger and more relevant. Thus, in the next section, investigating and assessing multiple mediation should involve two steps (MacKinnon 2000). First, the individual mediation effect of each mediator needs to be calculated. According to the regression results above, the mediation effect of process innovation is 0.048 (a_1*b_1=0.436*0.109), while the mediation effect of product innovation is 0.139 (a_2*b_2=0.318*0.541). Second, we need to contrast the difference of these two mediation effects. The value of the contrast is calculated as $f=a_1b_1-a_2b_2=-0.091$. Then, the formula derived by MacKinnon (2000) is used for the variance of a single pairwise contrast to assess the Z value: $var(f) = b_1^2\delta_{a1}^2 + b_2^2\delta_{a2}^2 + a_1^2\delta_{b1}^2 + a_2^2\delta_{b2}^2 - 2a_1a_2\delta_{b1,b2}$, $Z = f/sqrt(var(f)) = -0.913$ ($p>0.1$). This result suggests that the mediation effect of process innovation is slightly smaller than the mediation effect of product innovation, but this difference is not significant.

4.2 Supplementary analysis

Additionally, two robust tests are provided to make our results more robust. First, according to relevant research, industries with different intensities of pollution may differ in their responses to environmental regulations (Brío and Junquera 2003), so the 35 industrial sectors are divided into three groups according to pollution intensity. The pollution intensity of each industry is measured by the volume of industrial waste water, gas and solids[1]. Considering the different units of the three types of waste, we first standardize the three variables, calculate the weighted average with equal weight on an annual basis, and then obtain the historical average for each sector. Finally, we rank the 35 industrial sectors from top to bottom by pollution intensity. The top 10 sectors are classified as heavy pollution industries, the eleventh to the twenty-fifth are classified as moderate pollution industries, and the bottom ten are classified as light pollution industries. Sectoral names in terms of Standard Industrial Classification and the value of pollution intensity of the 35 industrial sectors are presented in Appendix A, Table A1[2]. Second, considering the

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[1] Here, solids are included because of the access to data, but solids are a very small proportion of these three pollutions, no more than 1%. This may also be the reason why the cost of facilities for the treatment of solids is not disclosed in the China Statistical Yearbook on Environment, because this cost is very small compared to the other two.

[2] According to a method from prior studies, we sum up the three types of waste with equal weights. Although the treatment using standardized data can remove the influence from unit inconsistency, it also has ignored the weight between them. Here, we calculate the average weights of wasted water, gas and solids in each industry and then calculate Pollution intensity2 by summing the three wastes up using different weights, which gives us a similar ranking with the result from equal weights (Pollution intensity1, see Table A1 in Appendix A). In a similar way, the measurement of PACE

differences in environmental regulations between different regions, the PH is tested in the context of regions. 31 Chinese provinces, excluding Hong Kong, Macau, and Taiwan, are divided into eastern, central and western regions (see Table A2 in Appendix A). Third, other measurements of PACE are adopted in the supplementary analysis. Although simply summing the cost of facilities for the treatment of waste gas and water up is a traditional approach, it obviously has its shortcoming, e.g., not considering the weight between them. Here, we overcome this problem by using a robust check by calculating the average weights of two abatement expenditures on wasted water and gas in each industry.

Supplementary empirical results have shown a consistency with the main analysis despite slightly different consequences in three kinds of industry. In the light pollution industries, both process innovation and product innovation have a positive and significant mediation effect on the relationship between environmental regulation and performance, and the mediation effect of product innovation is stronger than that of process innovation. However, in the moderate and heavy pollution industries, there is not a significant mediation effect (see the results in Appendix B, Table B1 to Table B3, Figure B1). Based on the data from the regional level, empirical results indicate that product innovation shows a stronger mediation effect than process innovation on the relationship between environmental regulation and performance in all regions (see the results in Appendix B, Table B4 to Table B6, Figure B4 to Figure B6). The third test from different measurements of PACE also shows a robust result (see Table B7 and Figure B7 in Appendix B).

5. Discussion and conclusion

Over the past twenty years, much has been written to discuss the relationship between environmental regulation, innovation, and performance, based on the Porter Hypothesis. However, existing studies show an unclear understanding of innovation in the PH. Little research has distinguished between the innovation forms mentioned by the PH. To extend prior studies on this topic and deepen our understanding on the innovation element of the PH, this paper provides a mediation model to explore how two innovation forms, process innovation and product innovation, mediate the relationship between environmental regulation and performance. Through an analysis of 35 industrial sectors in China from

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2001 to 2010, we find that both process innovation and product innovation play a partial mediating role in the relationship between environmental regulation and performance, and the mediation effect of product innovation is slightly stronger than that of process innovation.

Furthermore, our empirical results can be divided into two steps to show the mediation effect of innovation forms in the PH. In the first step of this casual chain, in which environmental regulation affects innovation, our empirical results clearly show that the stimulation of environmental regulation on process innovation is stronger than on product innovation. This result indicates that firms are more likely to adopt technology improvement to control pollution rather than higher-risk product innovation investment when they face external pressures from environmental regulations. However, the results of the second step reveal that product innovation is more advantageous than process innovation in the influence on firm performance. This suggests that process offsets caused by process innovation in the product process is weaker than product offsets caused by product innovation. Similar to the arguments of the PH, firms will respond to external environmental regulation using different innovation forms. Our study offers an inspection of the different mediating roles of these two innovation forms in the PH. According to the empirical data, there are real differences between process innovation and product innovation. Next, to make our main test robust, some complementary work is provided. In the light pollution industries, product innovation also shows a stronger mediation effect than process innovation. Light pollution industries do not produce a relatively high level of pollutants, instead, the high cost of abatement technologies may diminish performance for these firms. In the heavy pollution industries, although the stimulation of environmental regulation to two innovation forms exists, both innovation forms do not have a significant influence on performance. The reason for this may be that the benefits from innovation cannot offset their investment in the treatment of heavy pollution. In the three different regions, empirical results remain stable, with product innovation showing a stronger mediation effect than process innovation.

Our empirical study contributes to the ongoing literature in several ways. First, we extend the environmental management literature from the perspective of innovation management. Our research provides a deep understanding on the innovation in the PH, by distinguishing process and product innovation forms, and comparing their different roles in the relationship between environmental regulation and performance. Through different innovation forms, the conflict between regulation and economic development can be relieved. Meanwhile, there is also an implication for our innovation research. Future studies should pay more attention to how to use innovation management to resolve problems in other fields, such as the environmental field. Second, we develop a comprehensive framework to test the PH. To date, most literature has analyzed the impact of environmental regulation on innovation and on performance separately. In a mediation model, our study embraces the three elements involved in the PH, environmental regulation, innovation, and performance, and tests the weak version and strong version of the PH simultaneously. Such a whole model can enhance our understanding of the relationship chain in the PH.

Moreover, these findings can offer practical implications for managers and environmental policymakers. For companies, managers should regard environmental regulations as positive stimuli, rather than negative pressures. Different innovation forms can be deployed to respond to external shifts or pressure, but they have varying degrees of innovation offsets in the operating process. Adopting process innovation or product innovation, depends on a firm’s strategy. However, not all innovation investment is profitable for firm performance, so innovation managers should be cautious when deciding on the innovation forms chosen. For policymakers in developing countries, our results indicate that environmental regulation can encourage innovation to some extent. The conflict between the environment pollution and economic development may be alleviated through innovation stimulation. Consequently, the Chinese government and other developing country governments should insist on environmental regulation to an appropriate extent. If they could make sound environmental regulation policies to goad firms’ innovation, it is possible to achieve pollution reduction and economic performance increases simultaneously. However, it should be noticed that regulation effects differ for different pollution-intensity industries, so corresponding and specific policies should be made according to particular features of various industrial sectors. For example, for the traditional heavy pollution industries, environmental policies should focus not only on their end-of-pipe abatement but also encourage green production (Wan Alwi, Klemeš, and Varbanov 2016).

Our study also suffers from some limitations that could be addressed in future research. First, we focus only on the distinguishing of innovation forms. Other problems about innovation itself in the PH also deserve exploration from the perspective of innovation management. For example, what innovation strategies do firms take when the external environmental regulation becomes stricter- investing in research and development by themselves or buying advanced technology from other firms? Combining environmental management and innovation management may be an interesting topic for future research on the PH. Next, we test the relationship between environmental regulation innovation and performance in a comprehensive framework. As many scholars note, the effect of regulation on innovation and innovation on performance may work over the long term. Studies can explore the dynamic changes of these relationships among the three elements over time. Third, this is an empirical study on the examination of the PH in a Chinese context. Future studies can test this full model in other developing and emerging economies to make these findings more generalized.

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Appendix A:

Table A1.

Industrial classification by the pollution intensity.

Types of pollution	Names of industrial sectors	Pollution intensity1	Pollution intensity2
Light pollution industries	Manufacture of Articles for Culture, Education and Sport Activity	0.0005	0.0005
	Printing, Reproduction of Recording Media	0.0011	0.0015
	Manufacture of Furniture	0.0013	0.0018
	Manufacture of Tobacco	0.0042	0.0052
	Production and Supply of Gas	0.0058	0.0059
	Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work	0.0073	0.0102
	Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm, and Straw Products	0.0091	0.0130
	Manufacture of Textile Wearing Apparel, Footwear, and Caps	0.0101	0.0202
	Manufacture of Electrical Machinery and Equipment	0.0125	0.0205
	Production and Supply of Water	0.0156	0.0233
Moderate pollution industries	Extraction of Petroleum and Natural Gas	0.0156	0.0233
	Manufacture of Special Purpose Machinery	0.0156	0.0239
	Manufacture of Rubber and Plastics	0.0182	0.0286
	Manufacture of Leather, Fur, Feather and Related Products	0.0182	0.0343
	Manufacture of General Purpose Machinery	0.0199	0.0453
	Mining and Processing of Nonmetal Ores	0.0259	0.0467
	Manufacture of Communication Equipment, Computers and Other Electronic Equipment	0.0287	0.0483
	Manufacture of Metal Products	0.0307	0.0509
	Manufacture of Transport Equipment	0.0405	0.0604
	Manufacture of Foods	0.0457	0.0878
	Manufacture of Medicines	0.0524	0.0989
	Manufacture of Beverages	0.0592	0.1089
	Manufacture of Chemical Fibers	0.0606	0.1115
	Processing of Petroleum, Coking, Processing of Nuclear Fuel	0.1181	0.1346
	Processing of Food from Agricultural Products	0.1237	0.1703
Heavy pollution industries	Smelting and Pressing of Non-ferrous Metals	0.1557	0.2403
	Manufacture of Textile	0.1905	0.4459
	Mining and Processing of Ferrous Metal Ores	0.1943	0.4678
	Mining and Processing of Non-Ferrous Metal Ores	0.2418	0.4886
	Manufacture of Non-metallic Mineral Products	0.2710	0.5282
	Mining and Washing of Coal	0.2769	0.5596
	Manufacture of Paper and Paper Products	0.3617	0.6712
	Manufacture of Raw Chemical Materials and Chemical Products	0.4688	0.6728
	Smelting and Pressing of Ferrous Metals	0.6413	0.9009
	Production and Supply of Electric Power and Heat Power	0.8670	0.9091

Table A2.

Regional classification by provinces.

Regions	Names of provinces	Regions	Names of provinces
The east	Beijing	The west	Guangxi

	Tianjin		Chongqing
	Hebei		Sichuan
	Liaoning		Guizhou
	Shanghai		Yunnan
	Jiangsu		Xizang
	Zhejiang		Shaanxi
	Fujian		Gansu
	Shandong		Qinghai
	Guangdong		Ningxia
	Hainan		Xinjiang
The center	Shanxi	The center	Jiangxi
	Neimenggu		Henan
	Jilin		Hubei
	Heilongjiang		Hunan
	Anhui		

Appendix B:

Table B1.

Regression results (light pollution industries).

Variables	Model (1) Performance	Model (2) Process Innovation	Model (3) Product Innovation	Model (4) Performance
ER_{t-1}	0.652**	0.375**	0.207*	0.329
	(0.316)	(0.179)	(0.115)	(0.323)
Process $innovation_{t-1}$				−0.090
				(0.169)
Product $innovation_{t-1}$				0.913***
				(0.310)
Size	−0.941	0.502**	0.934***	−1.505**
	(0.617)	(0.226)	(0.228)	(0.647)
Leverage	0.567	1.290***	0.0789	0.587
	(0.903)	(0.471)	(0.331)	(0.870)
Macropolicy	1.801***	−0.627**	0.913***	0.921*
	(0.452)	(0.268)	(0.170)	(0.530)
Constant	10.96	−0.0698	−3.665	12.95*
	(7.385)	(2.927)	(2.782)	(7.158)
Observations	90	90	90	90
Wald chi^2	42.49	18.19	173.8	62.35
Number of industry	10	10	10	10

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

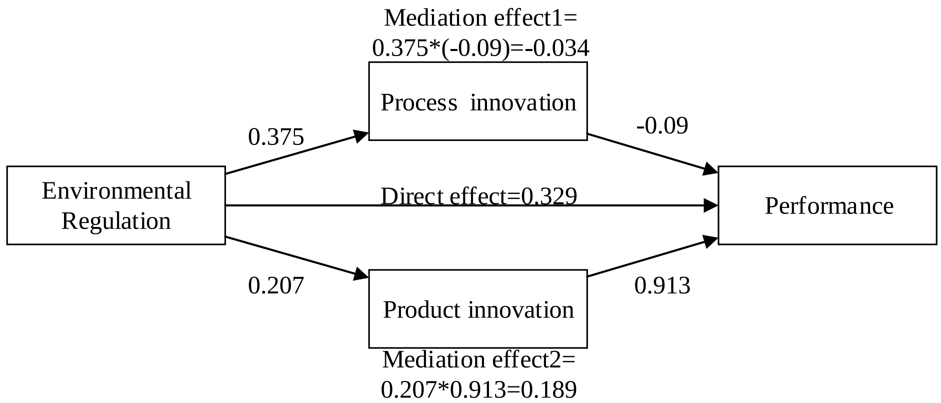

Figure B1.

Model parameters (light pollution industries).

Table B2.
Regression results (moderate pollution industries).

Variables	Model (1) Performance	Model (2) Process Innovation	Model (3) Product Innovation	Model (4) Performance
ER_{t-1}	0.550	0.178	0.092	0.562
	(0.711)	(0.219)	(0.116)	(0.718)
Process $innovation_{t-1}$				−0.110
				(0.176)
Product $innovation_{t-1}$				−0.0568
				(0.503)
Size	−0.560	0.436	1.375***	−0.412
	(1.050)	(0.284)	(0.168)	(1.279)
Leverage	14.78***	3.120**	0.458	14.96***
	(2.893)	(1.390)	(0.502)	(2.941)
Macropolicy	0.0837	−0.840***	0.738***	0.0646
	(0.657)	(0.281)	(0.113)	(0.798)
Constant	−6.109	1.551	−8.207***	−6.390
	(13.07)	(3.931)	(2.115)	(13.79)
Wald chi^2	38.55	15.70	446.00	38.10
Observations	135	135	135	135
Number of industry	15	15	15	15

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table B3.
Regression results (heavy pollution industries).

Variables	Model (1) Performance	Model (2) Process Innovation	Model (3) Product Innovation	Model (4) Performance

ER_{t-1}	1.493*	0.623***	0.751***	1.569*
	(0.831)	(0.214)	(0.138)	(0.879)
Process innovatin$_{t-1}$				0.292
				(0.209)
Product innovatin$_{t-1}$				0.059
				(0.609)
Size	7.494***	0.898***	1.638***	7.091***
	(2.183)	(0.211)	(0.370)	(2.471)
Leverage	16.698***	2.158*	1.401***	16.14***
	(2.744)	(1.176)	(0.475)	(2.801)
Macropolicy	−1.717*	−1.115***	0.345**	−1.734
	(0.982)	(0.364)	(0.156)	(1.066)
Constant	−130.159***	−8.870***	−21.91***	−129.4***
	(28.30)	(3.413)	(0.317)	(31.21)
Wald chi^2	61.79	57.20	351.1	62.05
Observations	90	90	90	90
Number of industry	10	10	10	10

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table B4.
Regression results (the east).

Variables	Model (1) Performance	Model (2) Process Innovation	Model (3) Product Innovation	Model (4) Performance
ER_{t-1}	0.080**	0.054	0.303***	0.004
	(2.272)	(0.526)	(3.812)	(0.110)
Process innovatin$_{t-1}$				0.007
				(0.220)
Product innovatin$_{t-1}$				0.238***
				(5.408)
Size	0.351***	1.031***	0.844***	0.157***
	(6.931)	(5.819)	(6.909)	(2.801)
Leverage	0.472	-0.909	1.663**	0.127
	(1.563)	(-0.981)	(2.274)	(0.452)
Macropolicy	-0.351***	-0.092	-0.705***	-0.148***
	(-9.064)	(-0.792)	(-7.987)	(-3.064)
Constant	-2.852***	0.601***	(13.107)	(-3.909)
	(-4.611)	(-0.269)	(-2.304)	(-3.909)
Wald chi^2	389.3	82.42	426.3	570.5
Observations	99	99	99	99
Number of province	11	11	11	11

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

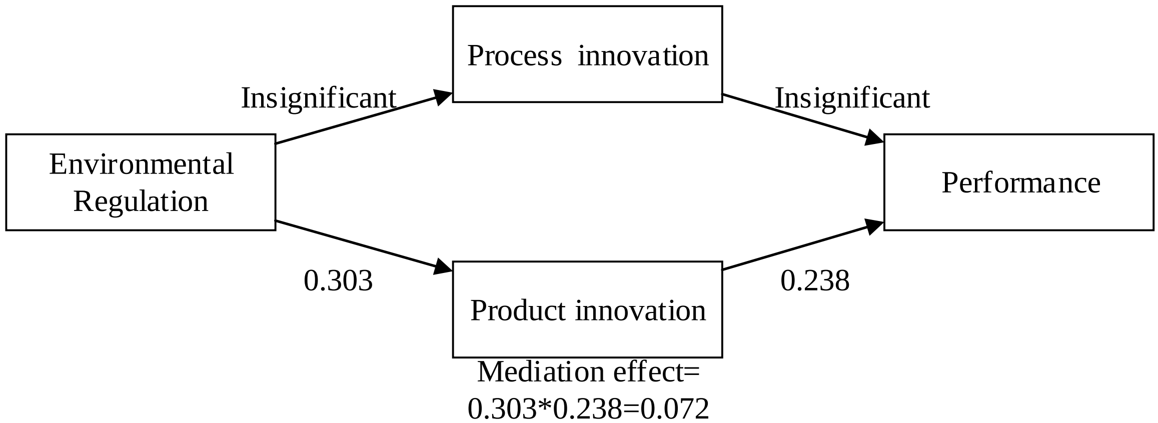

Figure B4.
Model parameters (the east).

Table B5.
Regression results (the center).

Variables	Model (1) Performance	Model (2) Process Innovation	Model (3) Product Innovation	Model (4) Performance
ER_{t-1}	0.203***	0.282***	0.322**	0.118**
	(3.378)	(2.911)	(2.559)	(2.085)
Process $innovatin_{t-1}$				0.040
				(0.506)
Product innovatin $_{t-1}$				0.248***
				(4.142)
Size	0.839***	0.420*	0.944***	0.571***
	(4.752)	(1.717)	(2.813)	(3.488)
Leverage	0.452	-1.487*	-0.721	0.318
	(0.857)	(-1.650)	(-0.632)	(0.687)
Macropolicy	-0.348***	-0.149	-0.919***	-0.084
	(-5.011)	(-1.335)	(-6.252)	(-1.054)
Constant	-11.107***	0.305***	(3.309)	(-5.074)
	(-5.055)	(2.043)	(11.806)	(-5.074)
Wald chi^2	325.8	70.47	238.2	463.6
Observations	81	81	81	81
Number of province	9	9	9	9

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

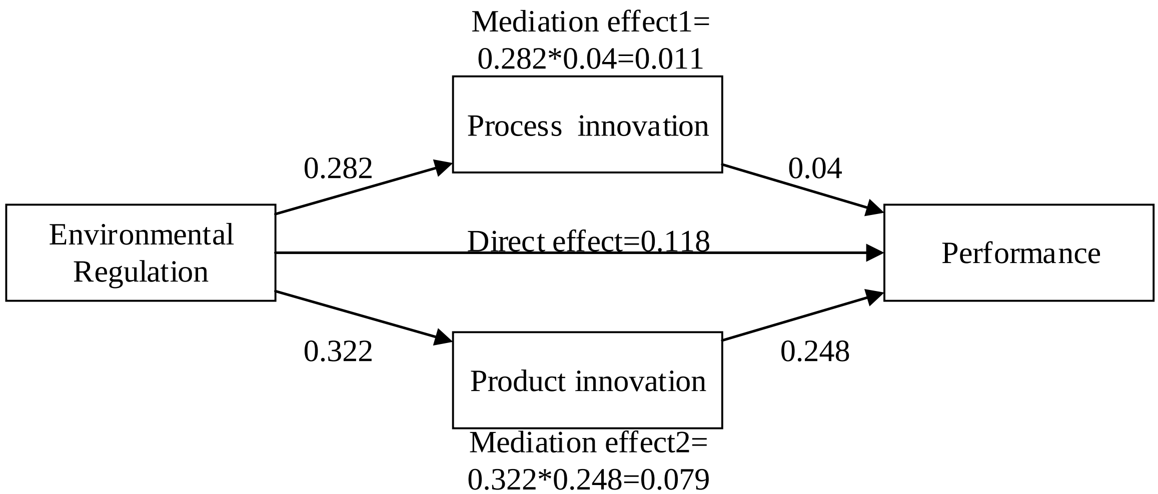

Figure B5.
Model parameters (the center).

Table B6.
Regression results (the west).

Variables	Model (1) Performance	Model (2) Process Innovation	Model (3) Product Innovation	Model (4) Performance
ER_{t-1}	0.202***	0.182**	0.380***	0.059
	(3.651)	(2.170)	(3.974)	(1.026)
Process innovatin$_{t-1}$				0.111*
				(1.812)
Product innovatin$_{t-1}$				0.256***
				(4.399)
Size	0.365***	0.851***	0.916***	0.030
	(3.170)	(4.986)	(5.025)	(0.220)
Leverage	0.371	-0.254	1.825***	0.208
	(0.858)	(-0.388)	(2.622)	(0.463)
Macropolicy	-0.372***	-0.215**	-0.712***	-0.169**
	(-5.266)	(-1.981)	(-5.950)	(-2.090)
Constant	-4.496***	0.390***	0.489***	-2.827*
	(-3.043)	(0.025)	(-2.569)	(-1.788)
Wald chi^2	211.1	138.4	323.5	257.0
Observations	91	91	91	89
Number of province	11	11	11	10

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Note: There is some missing data in the west provinces.

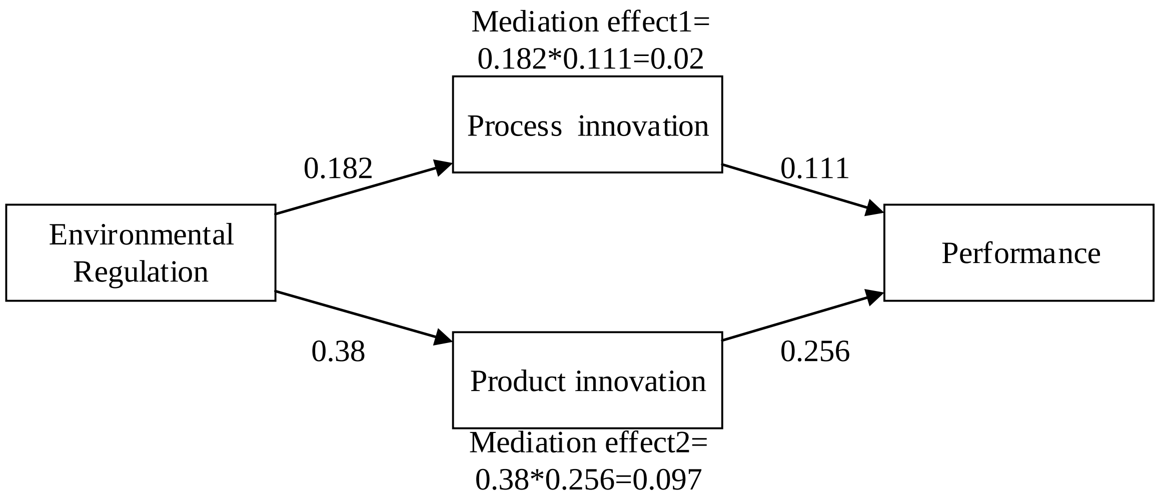

Figure B6.
Model parameters (the west).

Table B7.
Regression results (other measurement of PACE).

Variables	Model (1) Performance	Model (2) Process Innovation	Model (3) Product Innovation	Model (4) Performance
ER_{t-1}	0.591*	0.368***	0.237***	0.456
	(1.890)	(4.337)	(3.827)	(1.424)
Process $innovatin_{t-1}$				0.108
				(0.890)
Product $innovatin_{t-1}$				0.535*
				(1.831)
Size	0.303	0.758***	1.189***	-0.398
	(0.505)	(5.458)	(10.163)	(-0.573)
Leverage	6.648***	1.495***	0.335	6.410***
	(5.966)	(3.749)	(1.519)	(5.722)
Macropolicy	0.554	-0.871***	0.796***	0.139
	(1.368)	(-5.399)	(10.048)	(0.288)
Constant	-10.045	1.231***	1.090***	-6.188
	(-1.310)	(-1.768)	(7.919)	(-0.778)
Wald chi^2	75.55	94.95	802.8	80.37
Observations	315	315	315	315
Number of industry	35	35	35	35

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

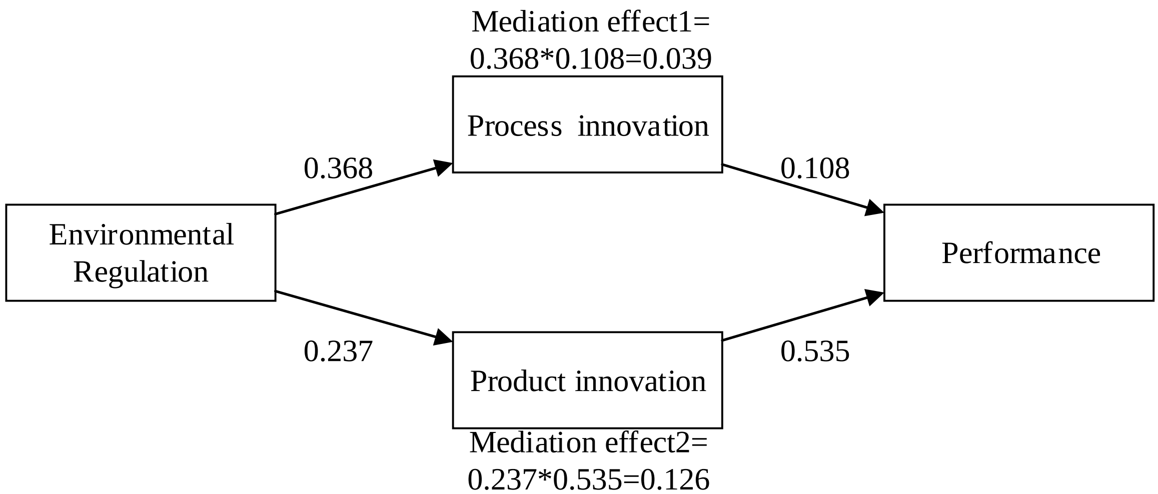

Figure B7.
Model parameters (other measurement of PACE).