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The Effects of Environmental Policy Stringency on Eco-innovation and Productivity Growth: A Country-level Analysis

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Abstract

This research paper investigates the effects of more stringent environmental policies on eco-innovation and productivity growth on a country-level based on the theory of the three versions of the Porter hypothesis. To do this, the main focus of this research paper is to specifically investigate the effects of more stringent market-based, non-market-based and technology support environmental policies on eco-innovation. Additionally, the effect of more stringent environmental policies on productivity growth and the mediating role of eco-innovation in this relationship are tested. For the analyses, fixed effects regressions on a sample of 39 countries over the period 2000-2018 are employed. The empirical results suggest that there is a positive significant effect of more stringent environmental policies on eco-innovation in support of the weak Porter hypothesis. Furthermore, non-market-based environmental policies have a positive significant effect on eco-innovation, while the estimates of the stringency of market-based and technology support environmental policies are insignificant which collides with the narrow Porter hypothesis. Lastly, there is no support for the strong Porter hypothesis as no significant mediating role of eco-innovation between more stringent environmental policies and productivity growth is found.

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1 Introduction

With the vast economic growth and significant increases in the consumption of natural resources over the last decades, the state of the current environmental climate has become more severe. Figures show that in response to the environmental pollution, national governments have adopted more stringent environmental policies as instruments to regulate greenhouse gas emissions (OECD, 2018). The stringency of environmental policies are the amount of implicit or explicit costs imposed on engaging in polluting activities (Earnhart & Rassier, 2016; OECD, 2018). Stringent environmental policies are the core of green policy-making. However, as more stringent environmental policies result in higher costs on pollutive production activities (Earnhart & Rassier, 2016), countries become more concerned about the potential impact of their environmental protection measures on their competitiveness (Dechezleprêtre & Sato, 2017). Neoclassical economists believe that more stringent environmental policies will lead to lower productivity and competitiveness as firms allocate their resources to complying with the increased production costs arising from these policies (Gray & Shadbegian, 2003; Palmer et al., 1995). On the other hand, Porter and Van der Linde (1995) opposed this view by arguing that more stringent policies can bring about more innovative activities as it will induce firms to discover previously unexplored technical approaches to minimize their pollution levels. The benefits of these innovative activities will offset the costs compliance, leading to increased competitiveness.

The introduction of this new view widely known as the Porter hypothesis, raised extensive interest regarding the subject matter followed by a wave of papers. Jaffe and Palmer (1997) explored this hypothesis further and categorized the arguments proposed by Porter and Van der Linde (1995) into three variants known as the weak, narrow and strong version of the Porter hypothesis (D’Agostino, 2015). The weak Porter hypothesis assumes that environmental policies stimulates eco-innovation, but this effect does not specifically improve competitiveness (Shi et al., 2022). The narrow hypothesis builds further upon this and suggests that market-based environmental policies, such as taxes, are better in inducing innovation compared to other forms of policies, as market-based environmental policies can provide businesses with more freedom to choose the best solution to deal with the increasing costs of compliance. Lastly, the strong version of the Porter hypothesis claims that the advantages of environmental regulation-induced innovation outweigh the costs of regulation, resulting in increased competitiveness.

Numerous academics have tested these proposed versions of the Porter hypothesis. However despite the increasing attention paid to the link between environmental policies, eco-innovation and competitiveness, the exact relationships between these factors are still unclear, which could be due to various factors. Firstly, although previous literature finds that more stringent environmental policies seem to encourage eco-innovation, there is substantial disagreement regarding the strength of this relationship. This could be attributed to the fact that the empirical studies primarily study the relationship between the stringency of environmental policies and eco-innovations without acknowledging the potential difference in effects between the types of environmental policies. Since Porter and Van der Linde (1995) specifically address that properly designed environmental policies trigger eco-innovation, the different characteristics in terms of design and implementation should also be considered. Unfortunately, limited studies have taken into account both the stringency and the variety of policies simultaneously in spite of the fact that multiple scholars argued for its importance and lack of attention (Iraldo et al., 2011; Xie et al., 2017). Secondly, according to the strong Porter hypothesis, the stringency of environmental policies, eco-innovation, and performance are interrelated. However, when considering this relationship, existing studies have studied the effects of more stringent policies on competitiveness neglecting the claims of the mediating role of eco-innovation (Hu et al., 2017). Recent country level studies who studied the strong Porter hypothesis assume that productivity increases resulted from more stringent environmental policies are due to an increased level of eco-innovation. However, this specific channel has not been tested on a country level to this date. From these observations in literature the following main research question is proposed:

What is the effect of more stringent environmental policies on eco-innovation and competitiveness?

To obtain this objective, building on the Porter hypothesis, this paper will firstly test the effect of more stringent environmental policies and three different forms of environmental regulatory policies on the number of environmentally related patent applications. Next, the role of eco-innovations in promoting competitiveness will be tested by examining the effects of the different types of policies on productivity growth while including the level of eco-innovations as a mediator. For these analyses, Baron and Kenny´s (1986) approach for mediation will be employed using fixed effects regressions with a dataset covering a sample of 39 countries, mostly OECD, over the period 2000-2018.

The contributions of this study to the existing literature regarding the Porter hypothesis are threefold. First, this empirical study adds to the literature by examining the effects of different forms of environmental policies and eco-innovation and competitiveness on a country-level.

The original hypothesis of Porter and Van der Linde (1995) proposes that more stringent environmental policies will have a positive effect on a country's level of competitiveness. However, much of the empirical literature testing the versions of the Porter hypothesis are firm- and industry level studies. There may be distinct differences between studies at different levels as for instance, for firm- and industry level studies the employed data sets are typically focused on specific firms and particular countries limiting the generalizability of the results (Kozluk & Zipperer, 2015). Second, this paper is believed to be the first to examine three groups of environmental policies by making use of the newly revised version of the Environmental Policy Stringency Index (EPS) developed by Kruse et al. (2022). Some existing literature has distinguished between the effects of market-based and non-market-based environmental policies. However, this paper extends this by investigating the effect of technology support environmental policies. Technology support environmental policies consist of feed-in tariffs and R&D subsidies and were first allocated in the category market-based and non-market-based environmental policies respectively. However, these forms of environmental policies operate differently from market and non-market-based environmental policies (Kruse et al., 2022). Therefore, this research will be the first to examine the role of technology supporting environmental policies on eco-innovation and competitiveness separately.

Finally, this paper will verify the role of eco-innovation proposed by Porter and Van der Linde (1995) by testing the mediating role of specifically eco-innovation on the relationship between more stringent policies and competitiveness. Studies have not investigated the differential effects of environmental policies on environmental innovation on a country level yet. Although the findings of some studies provide evidence of a mediating role of total innovation on the positive relationship between more stringent policies and competitiveness, they do not pay attention to the specific role of eco-innovation. As Porter and Van der Linde (1995) argue that eco-innovations induced by more stringent environmental policies will improve competitiveness, environmental innovation should be separated from other types of innovation. More specifically, from a theoretical perspective eco-innovation differs from regular innovation. The main objective of engaging in eco-innovations is considered ecological efficiency rather than economic gains (Jun et al., 2019). To better understand how environmental innovation affects the relationship between different types of environmental policies and competitiveness on a country level, it is important to study this mediating relationship.

The findings of this research are also relevant for policymakers. Over the years, policymakers have been more inclined to adopt non-market-based policies to address environmental damage. In developed nations, this policy form has become the largest component of the total environmental policies over the past twenty years. For EU countries for example, emission limits and technical requirements were the two most commonly used environmental policies (European Environment Agency, 2020; Schmitt & Schulze, 2011). Moreover, the stringency of technology support environmental policies for OECD countries has diminished during the last decade, prompting fears that the incentives to innovate in clean technologies may be dwindling. Given this preference for non-market-based environmental policies and decline in the others, this research aims to provide policymakers with novel knowledge regarding the effectiveness of different types of policies to present meaningful policy recommendations.

The paper's remaining sections are organized as follows. Chapter two and three review the main definitions and the existing literature on the stringency of environmental policies, eco-innovations and competitiveness along with proposed hypotheses. The fourth and fifth chapter present the data and methodology that will be used respectively, which is followed by the chapter six that provides the empirical results of the study. In chapter seven, a discussion regarding the results and a conclusion will be presented. The chapter will finish off with limitations and suggestions for future studies.

2 Main definitions and Theory

2.1 Stringency of Environmental Policies

The stringency of environmental policies can be defined as the amount of implicit or explicit costs imposed on engaging in polluting activities (Earnhart & Rassier, 2016; OECD, 2018). The introduction of more stringent environmental policies has arisen since pollution is a negative externality that regular market processes cannot solve. Excessive pollution activities arise from market failure due to the presence of negative externalities (Jackson, 1993). In this case, the market is not at its efficient output as the costs of pollution are not fully accounted for by the polluting individual or firms. This results in overproduction as the social costs are larger than the private costs resulting in excessive pollution (Pigou, 1920). The implementation of more stringent environmental policies is essential for correcting this environmental market failure by internalizing these private costs of environmental damage. Furthermore, environmental policies seek to address a second market failure which results in a lack of environmental innovation known as the double externality problem. Eco-innovations, unlike traditional innovations, bring about positive spillover effects at both innovation and diffusion stages. Firms have lower incentives to create eco-innovations in the presence of (positive) externalities as firms lack ownership rights over the newly acquired knowledge and are unable to reap the full benefits of environmental innovations (Cecere et al., 2014). This might lead to underinvestment in eco-technologies. As a result, environmental policies can play an important role in inducing firms to carry out eco-innovative activities despite the double externality problem by assigning a market value to environmental pollution (Cecere et al., 2014).

Over time, various proxies have been used to measure the stringency of environmental policies and can be grouped into four main categories: pollution abatement effort indicators, direct regulatory evaluations, indicators based on total emissions, and composite indicators (Galeotti et al., 2020). The most popular proxy for regulatory stringency used in previous studies regarding the Porter hypothesis is the measure of Pollution Abatement Costs and Expenditures (PACE). This is however not the best proxy for a country level study as the comparability of the PACE measure on a macro-level is questioned as there exists disparity in the sampling methods and definitions of pollution costs (Johnstone, 2012). To establish the effects of different types of more stringent environmental policies this research paper uses the Environmental Policy Stringency (EPS) index which is a composite indicator. As opposed to the other measurements of environmental stringency, the EPS index comprises of 13 different policy instruments which are categorized under market-based, non-market-based and technology support environmental policies which allows for assessment of the stringency of different forms of regulatory instruments (Kruse et al., 2022; Wang et al., 2019). The three categories of environmental policies all differ in terms of approach to regulate pollution. For instance, market-based environmental policies incentivize firms to improve their environmental performance through the introduction of prices or markets for polluting emissions (Stavins, 2003). Environmental taxes and tradable emission permits are the most common examples. Environmental taxes specifically tax firms for their pollution output while owning tradable permits allow firms to emit a certain amount of greenhouse gasses which can be traded if the firm pollutes more or less than allowed (Hall, 2004). Non-market-based environmental policies also referred to as command-and-control policies affect firm behavior by imposing specific requirements (Görlach, 2013). Non-market-based environmental policies refer to standards or objectives to reduce pollution levels (Pereira Sánchez & Vence Deza, 2015). When firms are not compliant to these policies sanctions are put in place. Examples of such policies are bans, emission limits and the implementation of specific technical process and production requirements. Lastly technical support environmental policies are policies that encourage the development of clean technologies and can be broken down in R&D subsidies and feed-in-tariffs (Kruse et al., 2022). R&D subsidies are financial tools that the government provides for R&D activities. Feed in tariffs can be defined as payments given to firms that produce their own green energy sources (Kim & Lee, 2012).

2.2 Eco-innovation

The central point behind testing the relationship between environmental policies and productivity is the question whether more stringent heterogenous environmental policies drive eco-innovation. Understanding how eco-innovations are defined is therefore important when investigating this relationship. In this research paper, eco-innovation can be defined as the development of new products or services which reduce environmental impacts (Díaz-García et al., 2015; Fussler & James, 1996; Munodawafa & Johl, 2019). There are two main categories of eco-innovations known as eco-product and eco-process innovations. The former refers to the process that involves improving or creating a new production method that contributes to environmental sustainability. The latter refers to the introduction of new or modified products that reduce the environmental impact (Ma et al., 2017). Eco-process innovations can be further divided into end-of-pipe technologies and eco-efficiency technologies. End-of-pipe pollution technologies involve adding equipment into the production process to capture the emissions while clean production technologies actually alter the production process to decrease emissions (Frondel et al., 2007). In this research paper terms such as environmental innovation, green innovation and innovation will all be used simultaneously to refer to the definition of eco-innovation.

To date, there is no consensus about which measure is most appropriate to measure eco-innovations. Most studies testing the weak Porter hypothesis either use data on green patents or R&D expenditures to evaluate (environmental) innovation performance (Hille & Möbius, 2019). Patent data is regarded as an intermediate output measure while R&D expenditures are considered an input measure of innovative activity (Kemp & Pearson, 2007; Park et al., 2017). In this research paper the number of green patents is the measure of choice. The main reason for this is that unlike R&D expenditures, patent data is available for a long time frame, and therefore will allow for more detailed predictions for this research. Moreover, patent data consist of patents of most technologies, specifically environmental technologies, whereas R&D expenditures of different technologies is rarely available. Companies do not wish to publish private R&D on individual technologies, and authorities do not require them to do so, hence information on private R&D on specific technologies is often not provided (Oltra et al., 2010). Although patent data is often used as a preferred indicator of innovation since it is strongly tied to the quantity and quality of innovations, there are several key limitations to be aware of. Firstly, patents measure invention. While invention is associated with innovation, it is not the same. For something to be considered an innovation, the invention must first be transformed and commercialized into a practical application (Roberts, 2007). Moreover, firms are more likely to file patents for environmentally related inventions that will lead to the development of new products instead of inventions that will result in new processes (Popp, 2005). Therefore, as a result of this, it must be kept in mind that the findings in this research paper regarding eco-innovations will mostly be relating to product innovations and process innovations that are end-of-pipe or alternative energy technologies (Oltra et al., 2010). Despite these limitations, the total number of green patents are the measure of choice in this research paper.

2.3 Environmental Policies, Eco-innovation and Competitiveness: Main theory

There has been much discussion about the relationship between stringent environmental policies and a nation's competitiveness. Over time, two key viewpoints have emerged known as the ‘pollution haven hypothesis’ and the ‘Porter hypothesis’. The pollution haven hypothesis, established by neoclassical trade economists, proposes that more stringent environmental policies have an adverse effect on countries' international competitiveness. Costs from more stringent policies require firms to shift their available resources from innovative activities to pollution prevention, slowing productivity levels which results in increases in product prices. Furthermore, environmental policies can effect competitiveness as product prices used for production will increase for firms as increased regulatory costs could potentially be passed through to product prices (Dechezleprêtre & Sato, 2017). The neoclassical economists define international competitiveness in terms of the relative price changes that are needed to achieve balanced trade. This notion of international competitiveness is measured using the real effective exchange rate and wage adjustments (Blecker, 1998). In line with this definition, it is therefore argued that the higher costs associated with implementing more stringent environmental policies negatively affects the competitiveness of countries, as this increases the wages and relative cost of export products -compared to imported products- for countries with stricter environmental policies (Qiang et al., 2022). The pollution haven hypothesis eventually proposes that due to the negative effects of the environment policies, affected firms are induced to relocate their pollutive activities to countries with less stringent environmental policies, thus creating pollution havens (Copeland & Taylor, 2004; Qiang et al., 2022).

On the other hand, the Porter hypothesis proposes that more stringent well designed environmental policies will have a positive effect on a country’s competitiveness as they will induce eco-innovations which will then potentially offset the regulatory costs. The thought behind this mechanism originates from Hicks (1932) who argued that a change in relative price of production factors will stimulate firms to develop new technologies to offset these costs. Porter (1991) adopted this notion and suggested that governments can increase the incentives for firms to develop new environmental technologies by controlling the prices of pollutive production factors (Porter, 1991; Porter & Van der Linde, 1995; Van Kemenade & Teixeira, 2017). This devised mechanism of Porter has been adopted and categorized into three variants known as the weak, narrow and strong Porter hypothesis by the scholars Jaffe and Palmer in 1997. The weak Porter hypothesis assumes that more stringent environmental policies stimulate environmental innovation as firms will try to reduce their compliance costs by developing new products and services. The strong version claims that the advantages of environmental regulation-induced innovation outweigh the costs of regulation, which result in increased productivity levels. Third, the narrow Porter hypothesis considers the flexibility of the different types of environmental policies. Porter and Van der Linde (1995) argue that market-based policies provide more freedom to choose better solutions to deal with the increasing costs of compliance which will positively affect eco-innovation compared to other forms of environmental policies. Unlike the definition of competitiveness from the pollution haven hypothesis, Michael Porter (1990) defines international competitiveness as the total productivity level of domestic firms. Conforming to this definition the Porter hypothesis argues for a positive relationship between more stringent policies and international competitiveness as environmental innovations over time offset the regulatory costs and result in increased firm productivity levels (Dechezleprêtre & Sato, 2017; Porter & Van der Linde, 1995).

Both viewpoints regarding the relationship of more stringent environmental policies and competitiveness are contradictory; however the notions are not mutually exclusive as their economic variables of interest and definitions of competitiveness differ. The pollution haven hypothesis studies the patterns of trade flows and foreign direct investment on relative prices (Bialek & Weichenrieder, 2021). The Porter hypothesis alternatively studies the effect of environmental innovation induced by environmental policies on productivity levels. This research paper's main objective is to explore the proposed versions of the Porter hypothesis. Hence, the definition for a nation's competitiveness will be the level of productivity and this word is from now on used in this research paper to refer to competitiveness.

3 Literature and Hypothesis Development

3.1 Stringent Environmental Policies and Eco-innovation

Over time many papers have tested the proposed versions of the Porter hypothesis. One strand of literature focuses on the relationship between more stringent environmental policies and environmental innovations thus the weak Porter hypothesis. Some scholars have conflicting arguments regarding the relationship between environmental policies and eco-innovation. The cost compliance theory, in line with neoclassical theory, proposes that more stringent environmental policies have an adverse effect on eco-innovation (Gray, 1987; Kalt, 1985). Scholars propose that more stringent policies provide firms with more costs without having profit opportunities, as for firms the benefits associated with green innovations do not exceed the costs of compliance (Jaffe et al., 1995; Palmer et al., 1995). Therefore, the increase in production costs associated with more stringent environmental policies requires firms to shift their available resources from innovative activities to pollution prevention instead of eco-innovating (Kemp & Pontoglio, 2011; Zhu et al., 2021). The same argument holds for technological support policies. The availability of technological support does not have to lead to an increase in eco-innovation as the use of the technological support by profit maximizing firms will go towards the development of new production technologies that are not as beneficial to the environment (Yu et al., 2016). Technological support can have a crowding out effect on the level of eco-innovative innovation due to the lack of supervision and the information asymmetry between the government and the private sector. Because of this the only firms that will engage in eco-innovation from technological support are located in low-end industries as these are the only firms that will see profit opportunities and benefit from the technological support (Yi et al., 2020).

On the other hand, the weak Porter hypothesis argues that more stringent environmental policies can positively influence innovation into environmental technologies (Porter, 1991; Porter & Van der Linde, 1995). The hypothesis lies on the assumption that, due to the existence of market failures, firms previously failed to acknowledge and undertake existing profitable opportunities with regards to environmental innovation (Martin & Scott 2000; Lanoie et al., 2011). These include high entry costs, imperfect competition, and asymmetric information. Pressures from more stringent environmental policies are thus said to be the driving force to the uncovering of these opportunities through the encouragement of innovations (Porter & Van der Linde, 1995). In turn, technological support policies induce eco-innovation as it reduces costs and the risk of engaging in these forms of innovative

activities. As a result, there will be an improvement in the efficient use of innovative input resources (Yi et al., 2020).
Overall, the weak Porter hypothesis has been fairly well supported. Most literature regarding this relationship is either on a firm level using data from surveys or utilized panel data for the industry-level papers (Brunnermeier & Cohen, 2003; Lanjouw & Mody, 1996; Popp, 2006). For specified findings of these empirical papers, this research paper refers to Kozluk and Zipperer (2015). Cross country studies on the other hand are limited and provide inconsistent results. To the best of my knowledge there are in total four cross country papers that assess the effects of more stringent policies on eco-innovation. De Vries and Withagen (2005) is the first and find a large positive effect on the relationship between the stringency of sulfur dioxide (SO2) policies and environmental patents related to SO2 reductions for a sample of 14 OECD countries over the years 1970 to 2000. The authors utilize a fixed effects model and controlled for endogeneity using an instrumental variable approach. Although the authors find a positive effect, the results are not robust to changes in the model. In contrast, Van Kemenade and Teixeira (2017) assess the relationship between environmental regulatory stringency and eco-innovation using several measures of eco-innovative performance and environmental stringency. Measures of eco-innovative performance that were included are the country's share of green exports relative to its total exports, the turnover of eco-industries and the employment in eco-industries. The measures of environmental stringency include the share of green taxes as a percentage of total GDP, firms current and future perceived stringency of environmental policies which includes both market and non-market-based types of environmental policies and lastly the perceived importance of the availability of government grants. Out of all the different measures environmental stringency that were examined, only green taxes show to be a significant determinant. This positive significant determinant however only is found for the turnover of eco-industries as a measure of eco-innovation (Van Kemenade & Teixeira, 2017). As a result, the authors conclude that environmental policy stringency has less of an impact on eco-innovation performance than initially hypothesized. The research paper did however come with methodological issues as the model was an ordinary least squares (OLS) model without country fixed effects.

Two more recent papers found a positive relationship between environmental policy stringency and green innovation (Ahmed, 2020; Galeotti et al., 2020). Using the OECD's Environmental Policy Stringency Index, Ahmed (2020) examine the long-run equilibrium link between environmental stringency and patents related to environmental technologies for 20 OECD nations from 1999 to 2015. The Pedroni and Panel Autoregressive Distributed Lag (PARDL) technique were applied for this purpose, and the results show positive effects in the long-run. Galeotti et al. (2020) studied whether various proxies of environmental stringency estimate similar conclusions on the relationship between environmental stringency and eco-innovation in 19 OECD countries from 1995 to 2009. The study reveals that within-country or between-country variance and conclusions about the relationship between environmental policies and eco-innovation are not robust across the three types of indicators widely used in literature which include pollution abatement effort indicators, composite indicators, and emission-based indicators. The authors find that the majority of the composite measures however, including the EPS index which will be used in this study, suggest that there is a small positive significant effect on environmental innovation relative to the total innovation level.

Considering the theoretical arguments and the aforementioned empirical findings on a country level pointing to positive eco-innovation effects, the first hypothesis is proposed:

H1: There is a positive relationship between more stringent environmental policies and eco-innovation at the country level.

Based on the findings above it can be hypothesized that more stringent environmental policies will induce eco-innovation. However, there are potentially differences in the effects of the specifications of environmental stringency measures and the strength of the positive effect. This could be explained by the various samples, empirical methodologies, and proxies for the stringency of environmental policy that are used in the existing literature about the relationship between more stringent environmental policies and eco-innovation. In addition, the studies do not distinguish between the different forms of environmental policies. The diversity of the research papers regarding the relationship between more stringent environmental regulations and eco-innovation makes it very hard to make conclusions. Acknowledging the difference between types of environmental policies employed in a country could offer some insight on the nature of the sign and the magnitude of the relationship between more stringent environmental policies and eco-innovation. This is because countries often utilize a combination of different forms of environmental policies which is not accounted for in most studies (Vollebergh, 2007). This could have consequences on the outcomes of the papers as scholars like Porter and Van der Linde (1995) suggest that flexible policies, such as market-based policies are better at inducing green technological innovation compared to other forms of policies.

3.2 Heterogeneous effects of Stringent Environmental Policies on Eco-innovation

From the literature review it can be stated that most country level studies support the broad notion that more stringent environmental policies induce innovation. However, there are different types of environmental policies which can have heterogeneous effects on green innovation levels. This is due to their differences in their characteristics. When it comes to the effects of more stringent policies and eco-innovation, Porter and Van der Linde (1995) propose that the way to create the maximum opportunity for innovation is for policies to be flexible referring to market-based policies, leaving the approach to innovation to firms and not the entity that sets the standards hence non-market-based and technology support policies. Based on the view of Porter and Van der Linde (1995), this research paper posits that the effectiveness of more stringent environmental policies critically depends on the flexibility of these policies.

The first step to show the difference in effectiveness of policies is to determine the difference in flexibility of the policies. There are two forms of flexibility namely within-firm flexibility and across-firm flexibility (Gayer & Horowitz, 2006). Within-flexibility refers to the flexibility the firm has in terms of deciding how to deal with the imposed environmental policies. Across-firm flexibility on the other hand is the ability of a firm to choose both from their own possible actions and other firms actions to reduce its pollution levels when faced with environmental policies (Gayer & Horowitz, 2006). Market-based environmental policies are characterized for having both within-firm flexibility and across-firm flexibility. Market-based policies demonstrate within-firm flexibility as they allow firms to choose the most appropriate technology solution and the timing of the implementation of the policies (Popp et al., 2010; Rothwell, 1992; Vollebergh, 2007). Furthermore, market-based environmental policies offer total across-firm flexibility as the price for polluting is equal for all firms and is tradable. As a result, the marginal cost of the final unit of pollution reduction will be the same for all businesses. Non-market-based environmental policies on the other hand are not as flexible. These policies lack across-firm flexibility as this regulatory form makes no distinctions between the imposed standards for polluters which require businesses to have to use their own methods to control their pollution levels (Stavins, 2003). Furthermore, emission limits do exhibit within-firm flexibility as it is possible to determine how to reach the goal of polluting less than the imposed limit. However, technological standards exhibit no within-firm flexibility as it mandates which pollution-control technologies should be used. Similar to non-market-based environmental policies, technology support policies do not have any across firm flexibility. Lastly, because only specific types of investments in energy efficiency get technological support, technological support environmental policies demonstrate very limited within-source flexibility (Gayer & Horowitz, 2006).

Next it can be argued that the flexibility of imposed environmental policies has consequences for the engagement of eco-innovative behavior. Theoretical and empirical literature has given importance to the role of flexibility as a determinant of eco-innovation. This can be explained by cost savings. The greater the within-firm and across-firm flexibility of environmental policies, the lower the costs of pollution control as firms have all the possibility to find the best way to achieve the lowest possible costs. With more within-firm flexibility the costs of dealing with environmental policies are entirely the responsibility of the polluter. This will reduce their costs compared to a situation where there is no within-firm flexibility as they have every incentive to take the actions that are less costly than the permit price or tax increasing eco-innovation. Furthermore the cost savings are higher when there is also across-firm flexibility because firms will search for the lowest cost actions across the entire regulated sector (Gayer & Horowitz, 2006). Moreover, by drawing upon the resource based view, more flexible environmental policies allow for a better use of a firm's available resources in comparison with less flexible environmental policies (Majumdar & Marcus, 2001). This is due to the fact that flexibility allows for more entrepreneurial behavior, creativity and risk taking (Majumdar & Marcus, 2001; Marcus, 1988; Strebel, 1987). Haščič et al. (2009) tested the role of flexibility and found evidence for the beneficial effect of "flexibility" of environmental policies on innovation using data of "environmental" patent applications from a cross-section of 73 nations.

Following the narrow Porter hypothesis and based on the theoretical and empirical findings regarding the characteristics of the different policies, this paper argues that there is heterogeneity in the relationships of more stringent environmental policies. It is proposed that more stringent market-based environmental policies positively affect eco-innovation levels as they are both within-firm flexible and across-firm flexible. More stringent non-market-based environmental policies are also argued to improve eco-innovation levels however less than market-based environmental policies as they offer within-firm flexibility. Moreover, due to the lack of with-in and across-firm flexibility technology support environmental policies are hypothesized to negatively affect eco-innovation.
This leads to the following hypotheses:

H2a: There is a positive relationship between more stringent market-based environmental policies and eco-innovation at the country level.

H2b: There is a positive relationship between more stringent non-market-based environmental policies and eco-innovation at the country level.

H2c: There is a negative relationship between more stringent technology support environmental policies and eco-innovation at the country level.

H2d: The relationship between more stringent environmental policies and eco-innovation differs per regulation such that more stringent market-based environmental policies have a stronger positive effect on a country's eco-innovation than more stringent non-market-based and technological support policies.

3.3 Stringent Environmental Policies and Productivity Growth

The conventional view regarding environmental policies portrays them as being detrimental to productivity growth. As aforementioned, this view assumes that firms are always profit maximizing and choose the optimal combinations for their production decisions. Therefore, more stringent policies that limit these choices will likely force them to make fewer decisions and potentially delay the development of new products. Furthermore, more stringent environmental regulation may also bring uncertainty about the future direction of a firm's operations. As firm decisions are typically created with existing regulatory structures in mind, uncertainty regarding future rules could impede both business investments and the development of new innovations (Gray & Shadbegian, 1995; Gray & Shadbegian, 1998). Besides these factors, more stringent policies pressure firms to increase their inputs to deal with regulatory compliance. If there is an increase in inputs, in this case inputs that are directly used for regulatory compliance, without an increase in production output, the total factor productivity would decrease (Barbera & McConnell, 1990). Productivity measures do not differentiate between inputs used for production and inputs used to comply with policies. This causes total inputs to be overstated and the total productivity level to be understated (Gray & Shadbegian, 1995; Gray & Shadbegian, 1998). The aforementioned arguments along with this mismeasurement effect fuels the belief that there is a negative effect between more stringent environmental policies and productivity.

Porter and Van Der Linde (1995) on the other hand suggests that environmental innovation resulting from more stringent environmental policies increases productivity through efficiency gains. Gains from eco-innovation results in higher resource productivity through for example more efficient resource use or the creation of higher quality products. They do argue that the positive effects of the induced eco-innovations tend to appear over a longer time period. This is because the process involved in developing environmental innovations usually takes some time for its benefits to yield (Porter & Van Der Linde, 1995). Moreover, the authors contend that eco-innovation can also take on another form which simply lessens pollution without improving the impacted product and/or processes. In this case the effects of more stringent environmental policies do not lead to a significant change in productivity.

Empirical literature regarding how environmental regulation impacts productivity or the strong Porter hypothesis is particularly controversial. Cohen and Tubb (2018) present a meta-analysis consisting of 107 papers that empirically investigate the relationship between environmental regulation and productivity. The results suggest that for the whole sample the effects of environmental regulation on productivity are about as likely to be positive as negative. However, when further identifying the effects the study finds that for papers studying the effects at a firm or industry level, the effects of environmental policies and productivity are more likely to be negative compared to regional or country level studies who find more positive effects.

Country level studies indeed point to positive effects for the relationship between environmental policies and productivity (De Santis et al., 2021; De Santis & Lasinio, 2016; Martínez-Zarzoso et al., 2019). Using a panel-quantile regression model, Martínez-Zarzoso et al. (2019) analyze data from 14 OECD countries from 1990 to 2011 to study the weak and strong Porter hypothesis. The results of the study show that environmental policies can have a positive influence on total innovation (R&D expenditures and patents) and productivity. Specifically, The EPS index has a significant positive relationship effect on total factor productivity in both the long and short run. Lastly, they did not find different coefficients across quantiles of the distribution of total factor productivity growth. Two other papers that addressed the effects of more stringent policies and productivity on a country level also tested whether there is heterogeneity in the effects of different policies; however conclusions regarding this assumption remain unclear. De Santis and Lasinio (2016) examine the impacts of more stringent policies on standard innovation, labor, and multifactor productivity growth by distinguishing between market-based and non-market-based environmental policies for a sample of European countries from 1995 to 2008. With regards to the effects on productivity, their findings are in line with the narrow Porter hypothesis as they found that more stringent market-based environmental policies stimulate innovation and productivity growth while non-market-based environmental policies are not a significant predictor of productivity growth.

On the other hand, De Santis et al. (2021) examine the relationship between 5 types of environmental policies and labor and multifactor productivity: taxes, trading schemes and feed-in-tariffs which are considered market-based policies and emission standards and R&D subsidies which fall under non-market-based environmental policies. The authors find that overall, the distinction between market- and non-market-based seems to be insignificant as their effects on productivity indices are comparable. Both studies however did find that standard innovation indirectly affects the positive effect of environmental policies on productivity.

3.4 Mediating Role of Eco-innovation

As aforementioned, the strong Porter Hypothesis' central claim is that eco-innovation mediates the relationship between more stringent environmental regulation and productivity growth. Empirical literature that tests the links between regulatory induced eco-innovations and productivity yield ambiguous results. Lanoie et al. (2011) are believed to be the first to acknowledge the whole relationship between environmental regulation, eco-innovation and productivity at the same time. Based on survey data that was conducted with over four thousand firms in 7 OECD countries, the study shows that more stringent environmental policies are positively related to the eco-innovation of firms. The study then used the predicted values of the induced eco-innovation from the regression that studies the relationship between environmental policies and eco-innovation to estimate the mediating role of eco-innovation. From this, the study finds that the values of the predicted eco-innovation are associated with a significant increase in business performance measured as the change in production. This conclusion supports the idea that regulation can stimulate innovation and improve the productivity of firms. On the other hand, Van Leeuwen and Mohnen (2017) investigate the way in which eco-innovation can improve productivity levels by employing a structural modeling approach on a panel of Dutch firms. The results of the study suggest that pollution-reducing environmental policies, that is, end-of-pipe, eco-innovations tend to reduce TFP levels.

Some studies have addressed the time dynamics of the indirect effects of eco-innovations (Marin & Lotti, 2017; Aldieri et al., 2021). Marin and Lotti (2017) find a negative relationship between environmental innovations and productivity from Italian manufacturing firms through studying the short term effects. The results of the study indicate that for polluting firms, eco-innovations exhibit negative productivity effects whereas for standard innovations the relationship is positive and significant. The findings are in line with the conventional view that firms engaging in eco-innovative behavior due to more stringent environmental policies leads to a crowding out effect of other innovations that have better outcomes in terms of enhancing productivity levels. Moreover, it is argued that the short term gains of eco-innovations are lower compared to standard innovations as the firms rely on new developed markets. The authors state however, that the gains from eco-innovations could be higher over the years as new markets are rapidly increasing yielding positive productivity effects (Marin & Lotti, 2017).

A more recent paper by Aldieri et al. (2021) agrees with previous literature that in the short run eco-innovations induced by environmental policies lead to less gains than standard innovations but argue that in the medium to long run these types of innovations will be beneficial for productivity growth. The authors of this study conducted an empirical analysis to determine the relationship between eco-innovations and productivity using fixed effects regressions on panel data including 85 Russian regions from 2010-2015. The findings of their empirical investigation indicate positive effects of induced environmental innovations on productivity.

Based on the proposed theory of Porter and Van der Linde (1995) and the empirical evidence of country level studies, this research paper proposes a positive relationship between more stringent environmental policies and productivity. This can be explained by the benefits of the induced innovations arising from the policies which will outweigh the costs of compliance. This effect however will be present in the medium-to long run instead of the short run:

H3a: In the short run, there is a negative relationship between more stringent environmental policies and productivity growth at the country level.

H3b: In the medium to long run, there is a positive relationship between more stringent environmental policies and productivity growth at the country level.

Momentarily, there are no country level studies that study the mediating role of eco-innovation. Therefore, this research paper bases the following hypotheses on the existing theory proposed by Porter and Van der Linde (1995):

H4: Environmental innovation mediates the relationship between more stringent environmental policies and productivity growth at the country level.

4 Data

4.1 Dependent variables

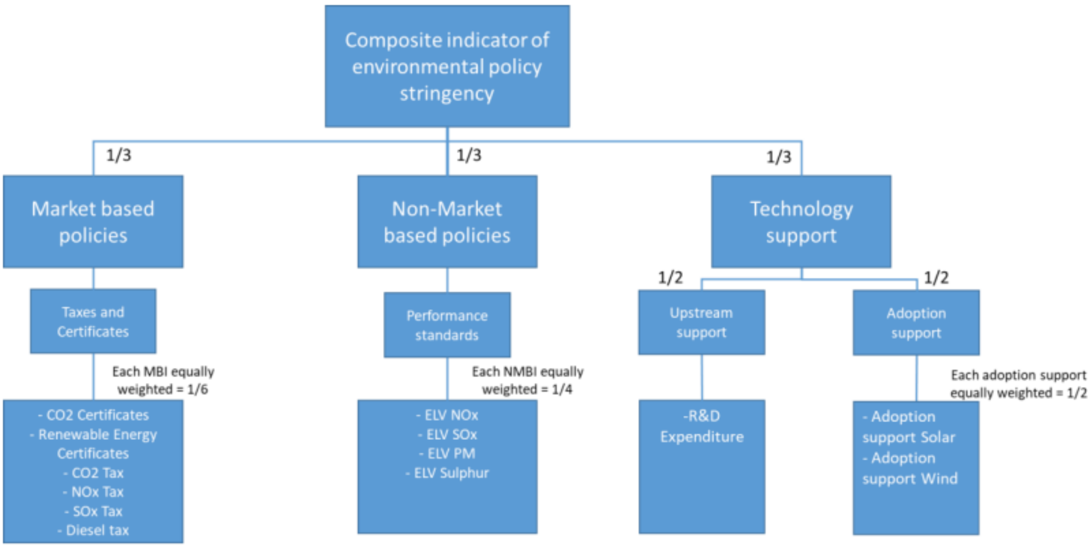
To measure the innovation and productivity effects of more stringent environmental policies, the dependent variables in this research paper are *Eco-innovation* and *Total Factor Productivity (TFP) Growth*. As aforementioned, the count of patent applications in environment-related technologies will be used as a proxy for country-level environmental innovation. This data is retrieved from the OECD Environments Statistics database (OECD, 2022). The values of this dataset are derived from the PATSTAT database, which is a global platform for collecting and analyzing patent information. This data is then filtered by using a search algorithm to specifically target technologies related to the improvement of environmental concerns. (Johnstone et al., 2012; OECD, 2022). In addition to being one of the main dependent variables in this research paper, environmental innovation also is the designated mediating variable. To measure the productivity effects, annual Total Factor Productivity (TFP) growth is utilized. Annual TFP growth, also known as Multifactor productivity growth (MFP) growth, reflects any growth of overall economic efficiency which cannot be assigned by changes in production inputs consisting of capital and labor. (Mahadevan, 2003; OECD, 2022). Data on the TFP levels is collected from the Penn World Table (PWT) version 10.0 database and converted in annual growth rates (Feenstra et al., 2015).

4.2 Independent variables

The independent variable in this research paper is *Environmental Policy Stringency (EPS*). This later divided into the environmental policy stringency of market-based, non-market-based and technological support environmental policies which are mid-level subindices of the EPS index. All data regarding the EPS index and subindices is retrieved from the OECD Economics department and belongs to the newly published working paper by Kruse et al. (2022) and is an extended version of the constructed EPS data by Botta and Koźluk (2014). The index of the policy instruments ranges from zero to six where the policy instrument is assigned a zero when the country does not engage in this form of policy instrument. The remaining values of countries that have implemented the policy are ordered from the least to the most stringent version of the policy instrument and are given a score based on the distribution of all these observations. In this way, the value six is allocated to observations that have policies in place that have values above the 90th percentile of all observations (Botta & Koźluk, 2014; Kruse et al., 2022). The variables of the different policy instruments in this way measure the stringency of the instrument across different time periods and relative to other countries. The variable *EPS: Market-based* consist of the aggregated indices of the stringency of taxes on CO2, Diesel, NOx and SOx and trading schemes. These first group are scored on the basis of the tax rate in euros per tonne. Trading schemes include CO2 emission trading schemes of and green (renewable energy) certificates. The scoring of these indices is based on the average annual permit price in euros. The variable *EPS: Non-market-based* includes the emission limit values of SOx, NOx and PM and are scored based on the limit value in mg/m3. Furthermore, the sulfur content limit for diesel is also included in this subindex and is assigned a score based on the limit value in parts per million (ppm). Lastly, the variable *EPS Technology Support* includes the total government's spending on R&D related to renewable energy technologies. This value is relative to the country's GDP and the magnitude of the value determines the score of its stringency value (Botta & Koźluk, 2014; Kruse et al., 2022). Lastly, the technological support also includes feed-in tariffs for wind and solar energy and renewable energy auctions; their score is determined by the level of support in euros per kWh. Figure 1 depicts the composition of the EPS index (Kruse et al., 2022).

Figure 1

Composition of the EPS Index



Note. Adapted from "Measuring environmental policy stringency in OECD countries: An update of the OECD composite EPS indicator," by T. Kruse, A. Dechezleprêtre, R. Saffar and L. Robert, 2022, OECD Economics Department Working Papers, No. 1703, OECD Publishing, Paris, p. 13. Copyright 2022 by OECD Publishing.

4.3 Control variables

Several country-level control variables are included in all the models to account for non-fixed country characteristics which explain the dependent variables. Country-specific drivers of eco-innovation and productivity growth are derived from existing literature on the determinants of these variables and earlier studies that evaluated the proposed variations of the Porter hypothesis at the country level. Based on previous research, besides regulatory factors, the drivers of country level environmental innovation can be categorized into technology push and market pull factors (Horbach, 2016). Technology push factors that will be included in the model are related to the technological capabilities of a country and its knowledge stock. These factors have a significant influence in the realization of eco-innovations as innovations are said to be dependent on sources of existing technological expertise (Ghisetti & Pontoni, 2015; Horbach, 2008; Horbach, 2016). This could especially be the case for eco-innovation as the research activities and information sources concerning eco-innovation are in its early stages. This research paper therefore includes the *R&D Expenditure* variable which captures gross domestic expenditures on R&D activities as a percentage of GDP. This includes activities undertaken by enterprises, research institutes and universities and its values are obtained from the World Bank’s World Development Indicators (WDI) (World Bank, 2022). Furthermore, a knowledge stock, in this case a *Patent Stock* variable is added to the model to account for previous environmental innovation activity. The value of the patents stock variable PS_{it} is derived with the following formula shadowing Han (2007):

$$PS_{it} = Ecopatents_{it} + (1 - \delta_{it})PS_{it-1}$$

The formula is composed of PS_{it-1} which is the patent stock of the preceding year in combination with $Ecopatents_{it}$ which is the current total count of eco patent applications. Furthermore, t stands for the time, δ is the depreciation rate, and i denotes the country. As the calculation of the current patent stock depends on the patent stock of the year before, a patent stock value at the base point is required. The patent stock at the base point PS_{i0} can be calculated using the following formula (Han, 2007):

$$PS_{i0} = \frac{1 + g_i}{g_i + \delta_i} * Ecopatents_{i0}$$

This formula consists of g_i which denotes the average growth rate of the eco patents, δ which is the depreciation rate and $Ecopatents_{i0}$ which stands for the total count of eco patents of the base year. To estimate the annual patent stocks, the depreciation rate is set at

15%, as this is the suggested value in line with existing literature regarding the calculation of patent stocks (Hall et al., 2005). Moreover, the growth rate of the eco patents is calculated based on the average of the growth rates two years before the base year.

Furthermore, to capture some form of market pull factors in this paper, this research paper uses *Renewable Energy Consumption* as a percentage of total energy consumption as a proxy to control for market demand and is found to have a positive direct relationship with eco-innovation (Irandoust, 2018). Furthermore, *Industry Value Added* as a percentage of GDP is added to the model to account for the differences in economic environments across countries (Hornbach, 2016). Moreover, derived from production literature, some additional control variables are added to the model. First, *Trade openness* and *Foreign Direct Investment (FDI)* are included as they are argued to influence innovative spillover effects and induces firms to innovate in order to stay competitive in their current market (Gehringer et al., 2016). Trade openness is defined as the value of total national imports and exports as a percentage of GDP and FDI is referred to as the net inflows of a country as a percentage of GDP (World Bank, 2022). The data of all the preceding variables is retrieved from the World Bank's WDI. Lastly, a measure of *Human Capital* is added to the model as it is acknowledged as a driver of TFP growth as literature finds a strong significant relationship between these variables. However, the sign of the relationship is still inconclusive as positive and negative effects on TPF growth are found in earlier studies (Benhabib & Spiegel, 1994; Engelbrecht, 2002; Sianesi & Van Reenen, 2003). The human capital index from the Penn World Table (PWT) version 10.0 is used in the model which is based on the mean number of years spent in school and an expected rate of return to school (Feenstra et al., 2015).

4.4 Descriptive statistics

The panel data set used in this research paper consists of 39 countries over the time period 2000-2018. The number of countries and (the) time frame(s) are based on the availability and consistency of the data. The dataset initially consisted of 40 countries however the United States had to be excluded as the values of TFP of the countries is relative to the TPF of the US (Feenstra et al., 2015). Therefore, the TFP of the US is equal to 1 for all years, hence it is not possible to determine any productivity effects. A list of the countries in the sample is illustrated in Appendix A. Moreover, the descriptive statistics of all the variables that are used in this research paper are presented in Table 1.

Table 1

Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Eco-innovation	741	351.407	860.881	0	7662.486
TFP growth	741	-.097	3.818	-14.394	19.27
EPS	741	2.183	1.125	0	4.556
EPS: Market-based	741	1.101	.837	0	4
EPS: Non-market-based	741	3.756	1.757	0	6
EPS: Technology Support	741	1.691	1.401	0	6
R&D Expenditure	673	1.719	.979	.048	4.941
Patent Stock	663	1737.207	4241.711	-279.941	32487.047
Renewable Energy Consumption	741	19.164	16.375	.692	78.214
Industry Value Added	741	26.379	6.654	10.427	48.061
Trade Openness	741	87.263	52.945	19.56	360.132
FDI	739	4.862	10.246	-57.532	86.479
Human Capital	741	3.113	.466	1.782	3.849

Moreover, a correlation matrix is presented in Table 2 to check for any multicollinearity issues. Significant strong correlation between independent variables is referred to as multicollinearity. Problems linked to multicollinearity may be biased standard errors and a loss of statistical power which negatively affects the interpretation of estimated coefficients (Mansfield, 1982; Shrestha, 2020). Literature suggests that a severe case of multicollinearity is assumed when the correlation between variables is above 0.8 (Gujarati, 2004). Table 2 of the Appendix indicates that most coefficients are below that threshold. However, some high correlations between variables are observed. The variables EPS Non-market-based and EPS Technology support (and EPS Market-based with a coefficient > 0.7), are highly correlated with the EPS index. The variables are subindices of the EPS index which explains the high correlation as they all measure environmental regulatory stringency. This however does not cause any concern as the subindices of the EPS index and the EPS index will not be simultaneously included in any regression analyses. Moreover, the variable Patent Stock is a function of Environmental Innovation which explains the high correlation between these variables. To avoid the risk of disregarding this high correlation value and any other sign of multicollinearity, Variance Inflation Tests (VIF) are executed as well and presented in Tables 1.1 and Table 1.2 in Appendix B. A VIF value higher than 10 is considered an indication of severe multicollinearity (Kutner et al., 2005). From the tests it can be seen that the VIF are well below 10 with a mean lower than 2 showing no evidence of severe multicollinearity.

Table 2

Correlation Matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1) Eco-innovation	1.000												
(2) TFP growth	-0.045	1.000											
(3) EPS	0.304*	-0.157*	1.000										
(4) EPS: Market-based	0.159*	-0.071	0.712*	1.000									
(5) EPS: Non-market-based	0.230*	-0.143*	0.916*	0.569*	1.000								
(6) EPS: Technology Support	0.349*	-0.156*	0.835*	0.405*	0.614*	1.000							
(7) R&D Expenditure	0.400*	-0.082*	0.322*	0.318*	0.204*	0.318*	1.000						
(8) Patent Stock	0.958*	-0.030	0.308*	0.158*	0.223*	0.358*	0.401*	1.000					
(9) Renewable Energy Consumption	-0.199*	0.013	-0.146*	0.087*	-0.217*	-0.131*	0.064	-0.189*	1.000				
(10) Industry Value Added	0.091*	0.186*	-0.264*	-0.144*	-0.205*	-0.292*	-0.153*	0.056	0.078*	1.000			
(11) Trade Openness	-0.210*	-0.006	0.329*	0.106*	0.367*	0.269*	-0.005	-0.203*	-0.194*	-0.236*	1.000		
(12) FDI	-0.100*	0.061	0.059	-0.045	0.099*	0.044	-0.054	-0.099*	-0.155*	-0.103*	0.390*	1.000	
(13) Human Capital	0.210*	-0.006	0.484*	0.409*	0.422*	0.393*	0.517*	0.236*	-0.186*	-0.185*	0.302*	0.038	1.000

5 Methodology

5.1 Regression Models

The main aim of this research question is to empirically investigate the relationship between more stringent (market-based, non-market-based and technology support) environmental policies, eco-innovation and competitiveness. To achieve this aim this research paper is divided into two main parts. Firstly, this study analyzes the effect of environmental policies on environmental innovation activity (weak and narrow Porter hypothesis). Second, this paper will investigate both the direct effect of more stringent environmental policies and Total Factor Productivity (TFP) growth and the indirect effect of eco-innovation in this relationship (strong Porter hypothesis). The primary method used to estimate the coefficients of interest is by using fixed effect models with clustered standard errors. The clustered standard errors account for heteroskedasticity across clusters of countries. The decision to use a fixed rather than a random effects model is determined by applying a Sargan-Hansen test for the regressions. The null hypothesis is that the unique errors and explanatory variables are uncorrelated and is in favor of a random effects model. regression. The alternative hypothesis proposes that there is correlation between the unique errors and explanatory variables and is in favor of a fixed effects model as a random effects model will be biased. This test is used instead of a Hausman specification test as this test does not allow for clustered standard errors. Results of the Sargan-Hansen test reject the null hypothesis for all regressions hence the fixed effects model will be more appropriate for estimating the models.
To test the first hypothesis stating that there is a positive relationship between more stringent environmental policies and eco-innovation, this research paper proposes a model based on previous literature (Jaffe & Palmer,1997; Rubashkina et al., 2015):

$$lnECOINNOVATION_{it} = \beta_0 + \beta_1 EPS_{it-q} + \sum_{k=1}^{N} \beta_k X_{kit-1} + \alpha_i + \gamma_t + \varepsilon_{it} \qquad (1)$$

Where $ECOINNOVATION_{it}$ denotes the total patent applications in environment-related technologies in country i and time t. In order to make the data of the eco-innovation variable more normally distributed, the natural logarithm of this variable is taken. To avoid undefined values a constant of 1 is added before taking the natural logarithm. EPS_{it-q} is the value of the environmental policy stringency index of country i and time $t-q$. Following previous studies, it is presumed that applying for a patent takes time as it follows a process of R&D and decision making which at least takes a year (Hall & Helmers, 2013; Rubashkina et al., 2015). Therefore, the environmental policy index is lagged one to three years where q

stands for the years lagged. X_{kit-1} stands for the set of control variables, described in paragraph 4.3, of country i and time $t-1$. To prevent simultaneity problems these variables are lagged 1 year; hence time represents $t-1$. The model also includes country fixed effects α_i and time fixed effects γ_t. Lastly, ε_{it} represents the error term.

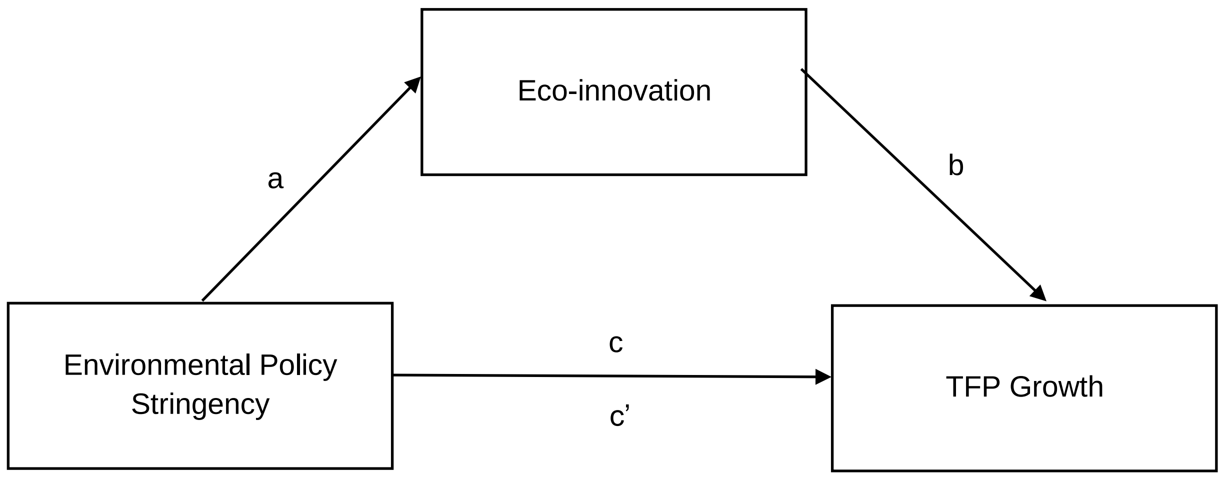
The second hypothesis proposes a differential effect between the types of environmental policies and eco-innovation. Therefore, the following model is based on hypothesis 1 however the environmental policy stringency index is divided into three variables:

$$lnECOINNOVATION_{it} = \beta_0 + \beta_1 EPS\ MB_{it-q} + \beta_2 EPS\ NMB_{it-q} + \beta_3 EPS\ TS_{it-q} + \sum_{k=1}^{N} \beta_k X_{kit-1} + \alpha_i + \gamma_t + \varepsilon_{it} \quad (2)$$

Where $EPS\ MB_{it-q}$ is the value of the market-based environmental policy stringency index of country i and time $t-q$. $EPS\ NMB_{it-q}$ denotes value of the non-market-based environmental policy stringency index of country i and time $t-q$. Thirdly, $EPS\ TS_{it-q}$ denotes value of the technological support environmental policy stringency index of country i and time $t-q$. Similar to the previous model all three environmental policy stringency variables are lagged one to three years represented by $t-q$.

Figure 2

Conceptual Mediation Model



Hypothesis 3a proposes that there is a negative effect of more stringent environmental policies on productivity growth in the short run. Moreover, Hypothesis 3b posits that there is a positive effect of more stringent environmental policies and productivity growth in the long run. In this research paper, short run effects are determined by looking at the effects of the models including no time lag, a one year lag and a two year lag. In turn for the medium-long term effect the estimate of the three year lagged variables is considered. Hypothesis 4 states that eco-innovation plays a mediating role in these relationships. To test the hypotheses this paper follows the mediation analysis procedure outlined by Baron and Kenny (1986). Figure 2 visualizes the conceptual model of the mediating role of eco-innovation in the relationship between more stringent environmental policies and TFP growth. The mediation analysis is done by estimating three main regression analyses. Firstly, a mediating relationship can be considered if there is a direct effect between more stringent environmental policies and productivity growth which is the illustrated c path in Figure 2. To determine this relationship the subsequent model is introduced:

$$TFPgrowth_{it} = \beta_0 + \beta_1 EPS_{it-q} + \sum_{k=1}^{N} \beta_k \ln X_{kit-1} + \alpha_i + \gamma_t + \varepsilon_{it} \quad (3)$$

Where $TFPgrowth_{it}$ is the value of the total factor productivity growth of country i and time t. The second model focuses on the a path of Figure 1 of the mediation analysis which is the relationship between the independent variable and the mediating variable. This relationship has already been estimated in model 1 which test for the effect of more stringent environmental policies and eco-innovation. For an established mediating relationship this relationship also has to be significant. Lastly, in the third model the independent and mediating variable are jointly present in the model which leads to the following regression model:

$$TFPgrowth_{it} = \beta_0 + \beta_1 EPS_{it-q} + \beta_2 lnECOINNOVATION_{it-q} + \sum_{k=1}^{N} \beta_k X_{kit-1} + \alpha_i + \gamma_t + \varepsilon_{it} \quad (4)$$

If the value of β_1 in model 4 is of a lower magnitude than in model 3, it can be stated that $lnECOPAT_{it-q}$ partially mediates the relationship between more stringent environmental policies and TFP growth. Full mediation is established if β_1 becomes insignificant or zero (Baron & Kenny, 1986). To determine the statistical significance of the mediation effect, this research paper makes use of the Sobel-Goodman test (Sobel, 1982).

6 Empirical Results

6.1 Stringent Environmental Policies and Eco-innovation

6.1.1 Hypothesis 1

Table 3 reports the regression results of the effect of the environmental policy stringency on eco-innovation. The columns present the coefficients of the impact of environmental policy stringency on the eco-innovation variable. The first column in Table 3 presents the effect of the current environmental policy stringency on eco-innovation and each column after presents an additional year lag period of the EPS variable. The last column therefore presents a 3 year lag period of the variable. To specifically determine the magnitude of the positive effects, it is important to note that the estimated models in Table 3 are log-level models. Therefore the coefficient estimates are interpreted by first exponentiating the coefficient. This number is then subtracted by one and multiplied by 100 to get the percent increase (or reduction) of the dependent variable for each unit increase in the independent variable (Woolridge, 2005).

According to Table 3, the stringency of environmental policies has a positive effect on eco-innovation on both the short and medium-long run. This effect is statistically significant at a 5% significance level for the present environmental policy stringency coefficient and at a 10% significance level for the lagged coefficients of environmental policy stringency in Table 3. From this, it can be stated that column (1) in Table 3 indicates that a one unit increase of the environmental policy stringency index, increases the total number of environmentally related patent applications by 17.4%, ceteris paribus. Furthermore keeping all other things constant the effects of a one unit increase of the one, two and three year lag of the environmental policy stringency index increases the total number of environmentally related patent applications by 14.1%,11.8% and 14.4% respectively. This effect thus decreases with the preceding years but seems to increase again after the second year lag.

With regards to the coefficients of the control variables added in the regression models, column (1) to (4) of Table 3 show that there are two variables that significantly affect eco-innovation on the short and medium-long run. Firstly, R&D expenditures has a positive relationship with eco-innovation which is significant at a 1% significance level. This indicates that a countries commitment of R&D plays a prominent role in stimulating eco-innovation, which is in line with the previous findings in literature. Furthermore, renewable energy consumption has a significantly negative effect on eco-innovation at a 1% significance level. This is contrary to the theorized positive effect of market demand on eco-innovation. Lastly, one interesting observation is that the coefficient of the patent stock variable is not significant. This indicates that the role of previously attained eco-innovation experience does not play a significant role in the level of eco-innovative activity.

Table 3

Fixed Effects Regression Results of the Effect of Environmental Policy Stringency on Eco-innovation

	Eco-innovation (Natural logarithm)			
	(1)	(2)	(3)	(4)
EPS	0.161**			
	(0.070)			
EPS (-1)		0.132*		
		(0.067)		
EPS (-2)			0.112*	
			(0.063)	
EPS (-3)				0.135*
				(0.071)
R&D Expenditures (-1)	0.428***	0.420***	0.405***	0.388***
	(0.108)	(0.109)	(0.110)	(0.111)
Patent Stock (-1)	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Renewable Energy Consumption (-1)	-0.018*	-0.019*	-0.020*	-0.021*
	(0.010)	(0.011)	(0.011)	(0.012)
Industry Value Added (-1)	0.003	0.003	0.002	0.002
	(0.016)	(0.016)	(0.016)	(0.016)
Trade Openness (-1)	-0.003	-0.003	-0.003	-0.004
	(0.002)	(0.002)	(0.003)	(0.003)
FDI (-1)	-0.001	-0.000	-0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Human Capital (-1)	0.594	0.610	0.625	0.657
	(0.577)	(0.586)	(0.597)	(0.596)
Constant	1.518	1.588	1.681	1.623
	(1.797)	(1.817)	(1.849)	(1.856)
Country Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
No. of observations	573	573	573	573
No. of countries	39	39	39	39
R^2	0.622	0.619	0.617	0.620

Note. Standard errors in parentheses. * indicates $p < 0.10$. ** indicates $p < 0.05$. *** indicates $p < 0.01$.

6.1.2 Hypothesis 2

Table 4 shows the estimates of the different types of environmental policy stringency on eco-innovation. In all of the four models the coefficient of the stringency of non-market-based environmental policies is positive and statistically significant, while the coefficients of market-based and technological support policies turn out to be insignificant. This indicates that non-market-based environmental policies are significantly accountable for the positive effect of more stringent environmental policies on eco-innovation. The interpretation of the coefficients of Table 4 is similar to Table 3. The columns present the coefficients in terms of timing and the estimated models are log-level models (Woolridge, 2005).

Keeping all other variables fixed, a one unit increase in the non-market-based environmental policy index of the current year increases the number of environmentally related patent applications with 11.9% . This effect is statistically significant at a 1% significance level. This effect decreases as the number of environmentally related patent applications increases by 8.5% for ever unit increase of the stringency index of non-market-based policies of the preceding year. This effect is again a bit lower for a one unit increase in the second year lag of the variable as the effect is then an increase of 8.4 % in eco-patent applications. Lastly, the effect of a one unit increase of the third year lag of the non-market-based policy stringency variable increases again compared to the second year lag and increases the amount of eco-patent applications with 10.4%, ceteris paribus. All the lagged effects are significant at a 5% significance level. The magnitude of the effects of more stringent non-market-based environmental policies on eco-innovation follows the same pattern as the results of the effects of the environmental policy stringency on environmental innovation of Table 3 in terms of time dynamics.

Concerning the control variables, compared to the results in Table 3, the effects of renewable energy consumption lost its significance in the models of Table 4. Furthermore, the effects of R&D expenditures remain positive and significant at a 1% significance level. Additionally, when there is a distinction between different forms of environmental policy stringency, the coefficients of the second and third year lagged patent stock variable do seem to have a positive and significant effect on eco-innovation and are significant at a 10% significance level. The magnitude of this effect however is negligible.

Table 4

Fixed Effects Regression Results of the Effect of Market-based, Non-market-based and Technology Support Environmental Policy Stringency on Eco-innovation

	Eco-innovation (Natural logarithm)			
	(1)	(2)	(3)	(4)
EPS: Market-based	0.020 (0.057)			
EPS: Non-market-based	0.113*** (0.035)			
EPS: Technology Support	0.017 (0.025)			
EPS: Market-based (-1)		0.017 (0.074)		
EPS: Non-market-based (-1)		0.081** (0.034)		
EPS: Technology Support (-1)		0.018 (0.026)		
EPS: Market-based (-2)			0.042 (0.078)	
EPS: Non-market-based (-2)			0.081** (0.037)	
EPS: Technology Support (-2)			-0.005 (0.022)	
EPS: Market-based (-3)				0.085 (0.085)
EPS: Non-market-based (-3)				0.099** (0.040)
EPS: Technology Support (-3)				-0.021 (0.020)
R&D Expenditures (-1)	0.383*** (0.103)	0.389*** (0.104)	0.368*** (0.107)	0.350*** (0.110)
Patent Stock (-1)	0.000 (0.000)	0.000 (0.000)	0.000* (0.000)	0.000* (0.000)
Renewable Energy Consumption (-1)	-0.015 (0.011)	-0.017 (0.011)	-0.018 (0.012)	-0.019 (0.012)

Industry Value Added (-1)	0.000	0.002	0.000	0.001
	(0.015)	(0.015)	(0.015)	(0.014)
Trade Openness (-1)	-0.003	-0.003	-0.003	-0.003
	(0.002)	(0.003)	(0.003)	(0.003)
FDI (-1)	-0.001	-0.000	-0.000	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Human Capital (-1)	0.587	0.608	0.660	0.720
	(0.589)	(0.593)	(0.607)	(0.603)
Constant	1.512	1.579	1.528	1.323
	(1.807)	(1.820)	(1.865)	(1.863)
Country Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
No. of observations	573	573	573	573
No. of countries	39	39	39	39
R^2	0.630	0.623	0.623	0.634

Note. Standard errors in parentheses. * indicates p < 0.10. ** indicates p < 0.05. *** indicates p < 0.01.

Additionally, to test whether the effects of more stringent environmental policies and eco-innovation differ for more stringent market-based (β_1), non-market-based (β_2) and technological support (β_3) environmental policies, Wald tests are conducted. Table 5 presents the results of the conducted tests and shows that the null hypothesis that market-based environmental policies are equal to non-market-based and technological support environmental policies cannot be rejected. Therefore there is no evidence that supports that there is a difference in the different types of environmental policy stringency.

Table 5

Results of Wald Tests

Regression Model of Table 4	Time Lag of Environmental Stringency Policy Indices	H_0	P-value
1	No lag	$\beta_1 = \beta_2$	0.131
		$\beta_1 = \beta_3$	0.960
2	One year lag	$\beta_1 = \beta_2$	0.419
		$\beta_1 = \beta_3$	0.991
3	Two year lag	$\beta_1 = \beta_2$	0.675
		$\beta_1 = \beta_3$	0.564
4	Three year lag	$\beta_1 = \beta_2$	0.891
		$\beta_1 = \beta_3$	0.221

Note. * indicates $p < 0.10$. ** indicates $p < 0.05$. *** indicates $p < 0.01$.

6.2 Stringent Environmental Policies and Productivity

6.2.1 Hypothesis 3

Hypothesis 3 proposes that the effect of more stringent environmental policies on productivity growth is negative on the short run and positive in the medium-long run. Similar to the previous tables, the columns present different coefficients in terms of timing. However now the interpretations of the coefficients are in line with a level-level model. The results for all the models reported in Table 6 indicate that environmental policy stringency does not have a significant direct effect on a country's level of TFP growth. Even though the effects are not significant, from the models, it can be seen that the coefficients turn more positive the higher the time lag is. For instance, the non-significant effect of environmental policy stringency is negative for the current, one year lag and the two-year lagged environmental policy stringency index however the non-significant effect of more stringent environmental policies of three preceding years on the current TFP growth is positive as seen in column (4) of Table 6.

Regarding the control variables, from Table 6 it can be seen that the control variables trade openness and FDI, which were specifically added in the model to account for productivity growth, are positive and significant at a 1% significance level and are in line with existing literature. Moreover, the potential effects of human capital were also specifically taken into account for TFP growth. As aforementioned, the sign of the effect of human capital has been found to be inconclusive in past literature as positive and negative effects have been discovered. The coefficient of the variable in this study is negative however does not have a statistically significant effect on TFP growth in all models presented in Table 6. On the other hand, a variable that did have an statistically significant effect at a 1% significance level on TFP growth is the industry value added variable. This indicates that countries with higher net output in the industry sector have significantly lower levels of TFP growth.

Table 6

Fixed Effects Regression Results of the Effect of Environmental Policy Stringency on Productivity Growth

	TFP Growth			
	(1)	(2)	(3)	(4)
EPS	-0.444 (0.368)			
EPS (-1)		-0.311 (0.463)		
EPS (-2)			-0.298 (0.390)	
EPS (-3)				0.072 (0.521)
R&D Expenditures (-1)	-0.026 (0.545)	-0.003 (0.547)	0.037 (0.546)	-0.010 (0.524)
Patent Stock (-1)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
Renewable Energy Consumption (-1)	0.049 (0.041)	0.054 (0.042)	0.055 (0.043)	0.054 (0.042)
Industry Value Added (-1)	-0.359*** (0.119)	-0.357*** (0.119)	-0.355*** (0.119)	-0.346*** (0.119)
Trade Openness (-1)	0.043*** (0.015)	0.043*** (0.015)	0.044*** (0.015)	0.043*** (0.015)
FDI (-1)	0.003** (0.012)	0.029** (0.012)	0.029** (0.012)	0.029** (0.012)
Human Capital (-1)	-2.035 (2.119)	-2.069 (2.144)	-2.116 (2.189)	-1.974 (2.120)
Constant	10.510 (8.043)	10.160 (8.328)	10.030 (8.376)	9.076 (8.198)
Country Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
No. of observations	573	573	573	573
No. of countries	39	39	39	39
R^2	0.223	0.222	0.222	0.221

Note. Standard errors in parentheses. * indicates $p < 0.10$. ** indicates $p < 0.05$. *** indicates $p < 0.01$.

Additionally, the effects of the stringency of different environmental policies on TFP growth are also analyzed and are presented in Table 7. Contrary to the results discussed in the previous paragraph, some lagged variables of the stringency of market-based and technology support environmental policies are found to significantly affect TFP growth in a country. The magnitude of the effect can be interpreted without any calculations as these are level-level regressions. Therefore, it can be stated from Table 7 that a one unit increase in the stringency of market-based environmental policies of three years before, results in a decrease in the current TFP growth of 0.86, ceteris paribus. This effect is statistically significant at a 10% significance level. Additionally, an one unit increase in the stringency of market-based environmental policies of two years before is associated with a 1.42 unit decrease in current TFP growth, ceteris paribus. This effect is statistically significant at a 5% significance level. The coefficient of technology support in model 4 of Table 7 shows that, keeping all other things constant, a one unit increase in the stringency of technology support environmental policies of three years before increases the level of TFP growth with 0.37. This effect is statistically significant at a 10% significance level. Furthermore, Table 7 shows that in addition to the previous model, renewable energy consumption also is a predictor of TFP growth as it has a positive significant coefficient at a 5% significance level.

Table 7

Fixed Effects Regression Results of the Effect of Market-based, Non-market-based and Technology Support Environmental Policy Stringency on Productivity Growth

	TFP Growth			
	(1)	(2)	(3)	(4)
EPS: Market-based	-0.682 (0.499)			
EPS: Non-market-based	-0.0105 (0.261)			
EPS: Technology Support	-0.133 (0.220)			
EPS: Market-based (-1)		-0.860* (0.471)		
EPS: Non-market-based (-1)		-0.0765 (0.265)		
EPS: Technology Support (-1)		0.0426 (0.218)		
EPS: Market-based (-2)			-1.423** (0.553)	
EPS: Non-market-based (-2)			-0.0875 (0.194)	
EPS: Technology Support (-2)			0.197 (0.225)	
EPS: Market-based (-3)				-0.446 (0.464)
EPS: Non-market-based (-3)				-0.204 (0.266)
EPS: Technology Support (-3)				0.373* (0.195)
R&D Expenditures (-1)	-0.0318 (0.565)	0.145 (0.589)	0.325 (0.597)	0.207 (0.503)
Patent Stock (-1)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)
Renewable Energy Consumption (-1)	0.062 (0.041)	0.067 (0.043)	0.084* (0.045)	0.055 (0.044)
Industry Value Added (-1)	-0.362*** (0.118)	-0.352*** (0.113)	-0.349*** (0.113)	-0.341*** (0.121)
Trade Openness (-1)	0.041** (0.015)	0.040** (0.015)	0.036** (0.014)	0.037** (0.015)
FDI (-1)	0.029** (0.011)	0.027** (0.012)	0.027** (0.010)	0.030*** (0.011)

Human Capital (-1)	-2.180	-2.322	-2.512	-2.313
	(2.143)	(2.189)	(2.270)	(2.174)
Constant	10.940	11.010	11.410	10.660
	(8.047)	(8.380)	(8.483)	(8.449)
N	573	573	573	573
No. of countries	39	39	39	39
R^2	0.225	0.226	0.235	0.228

Note. Standard errors in parentheses. * indicates $p < 0.10$. ** indicates $p < 0.05$. *** indicates $p < 0.01$.

6.2.2 Hypothesis 4

Lastly, to determine whether eco-innovation mediates the relationship between more stringent environmental policies and TFP growth, results of the different models are considered. As proposed by Baron and Kenny (1986), the first step in determining whether there is a mediation effect is if the stringency of environmental policies significantly affects productivity growth. In line with the results discussed in the previous paragraph, there is no statistically significant effect of more stringent environmental policies on TFP growth found in the models. Hence, there is no support for the hypothesis that eco-innovation mediates the relationship between environmental policy stringency and TFP growth as, statistically, there is no effect that can be mediated. Baron and Kenny (1986) propose not to continue the investigation of a mediation effect if the predictor does not affect the mediator. However, further analysis will be conducted to examine why this mediation relationship does not exist.

The second criterion of the mediation analysis proposed by Baron and Kenny (1986), in this research paper's case is that there is a significant relationship between more stringent environmental policies and eco-innovation. From the estimates presented in Table 3, which are widely discussed in paragraph 6.1.1, it can be derived that this is indeed the case as there is a positive and statistically significant effect of more stringent environmental policies on eco-innovation.

Baron and Kenny (1986) also present an extra step that estimates the effect of the mediating variable (eco-innovation) and the outcome variable (TFP growth), known as the 'b' path, which is presented in Table 1 in Appendix C. This is not an essential part of the actual mediation analysis as the mediator variable and dependent variable may have a statistically significant relationship due to independent variable which is not controlled for. However, results of the model regressing eco-innovation on TFP growth show that there is not a statistical significant effect of eco-innovation on TFP growth. This completely rules out the existence of an mediating relationship. For the last step of the mediation analysis the effect of more stringent environmental regulation on TFP growth includes eco-innovation as a control variable. The estimates are illustrated in Table 8. A mediating relationship can be concluded when the value of the stringency of environmental policies has decreased or lost its significance when including the mediating variable in the model compared to the model without the mediator. Table 8 shows that only the effect of the coefficient of the three year lagged environmental policy stringency variable (0.048) has decreased compared to the same coefficient (0.072) regressed on TFP growth without the mediator presented in Table 6. However as the coefficients are insignificant it cannot be supported that the introduction of the mediating variable has a significant effect on this decrease in value. The other estimates of the stringency of environmental policy have all increased compared to the estimates of the models without eco-innovation as a mediator ruling out any possible mediating effect. To confirm the interpreted results derived from the steps of Baron and Kenny (1986), Sobel-Goodman tests are conducted and presented in Table 9. In line with the interpreted results, all the estimates in Table 9 show that there is no statistically significant mediating effect of eco-innovation as the p-value is greater than 0.10 for all rows.

Table 8

Fixed Effects Regression Results of the Effect of Environmental Policy Stringency on Productivity Growth including Eco-innovation

	TFP Growth			
	(1)	(2)	(3)	(4)
EPS	-0.403			
	(0.377)			
Ln Eco-innovation	-0.253			
	(0.499)			
EPS (-1)		-0.283		
		(0.462)		
Ln Eco-innovation (-1)		-0.205		
		(0.470)		
EPS (-2)			-0.272	
			(0.402)	
Ln Eco-innovation (-2)			-0.272	
			(0.420)	
EPS (-3)				0.048
				(0.518)
Ln Eco-innovation (-3)				0.357
				(0.537)
R&D Expenditures (-1)	0.082	0.104	0.178	-0.180
	(0.456)	(0.560)	(0.558)	(0.625)
Patent Stock (-1)	0.000	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Renewable Energy Consumption (-1)	0.045	0.051	0.050	0.064
	(0.044)	(0.042)	(0.044)	(0.045)
Industry Value Added (-1)	-0.358***	-0.357***	-0.356***	-0.342***
	(0.120)	(0.119)	(0.119)	(0.120)
Trade Openness (-1)	0.042***	0.042***	0.043***	0.043***
	(0.015)	(0.016)	(0.015)	(0.015)
FDI (-1)	0.030**	0.029**	0.029**	0.029**
	(0.012)	(0.011)	(0.011)	(0.012)
Human Capital (-1)	-1.884	-1.849	-1.834	-2.350
	(2.083)	(2.140)	(2.279)	(2.175)
Constant	10.890	10.110	10.080	8.984
	(8.272)	(8.321)	(8.315)	(8.390)
N	573	573	573	573
No. of countries	39	39	39	39
R^2	0.223	0.222	0.222	0.222

Note. Standard errors in parentheses. * indicates $p < 0.10$. ** indicates $p < 0.05$. *** indicates $p < 0.01$.

Table 9

Results of Sobel-Goodman tests

Time frame of Eco-innovation and Environmental Policy Stringency variable	Test statistic	Standard Error	P-value
No lags	-0.650	0.083	0.516
One year lag	-0.513	0.065	0.608
Two year lag	-0.678	0.050	0.498
Three year lag	0.627	0.078	0.531

Note. * indicates $p < 0.10$. ** indicates $p < 0.05$. *** indicates $p < 0.01$.

In addition, when distinguishing between the different forms of environmental policy stringency there is a significant effect found between some lagged variables of the stringency of market-based and technology support environmental policies and TFP growth in a country as discussed in paragraph 6.2.1. This is in line with the first step of determining a potential mediating relationship (Baron and Kenny, 1986). However the second criterion of the mediation relationship is not satisfied as both stringent market-based and technology support environmental policies do not significantly affect eco-innovation as discussed in paragraph 5.1.2. Therefore it can be concluded that eco-innovation does not mediate any of the existing significant relationships between the different forms of environmental policies and TFP growth.

6.3 Robustness Test

To assesses the generalisation of the estimation results of this research paper a robustness test is conducted. This is done by altering the sample of the dataset on which the analyses of this research paper are based. To see whether the results differ when having different countries in the sample, the regression analyses are now examined by excluding the non-OECD countries in the sample. In total there are 7 non-OECD countries in the sample which are Brazil, China, India, Indonesia, Mexico, Russia and South Africa. Consequently, the sample of countries is now reduced from 39 to 32 countries. Tables 1 to 4 in Appendix D show the regression results of the main regression models that have been proposed in this research paper for the sample that only consists of OECD countries. When comparing the tables in Appendix D and the main results of the results section there are however some dissimilarities in the sign and significance of the results. The most notable difference is the effect of the general environmental policy stringency variable on eco-innovation. The results in Table 1 in Appendix D show that this effect is positive however not statistically significant for the limited sample. The sign of the effects are in accordance with Table 3 of the results section however the effect of this variable is significant in the base results. However, when distinguishing between the different stringent environmental policy forms illustrated in Table 2 of Appendix D, the results are in line with the initial results of the research as the effect of non-market-based policies on eco-innovation are positive and significant as well. Furthermore, Table 2 in Appendix D, shows that both market-based and technology support environmental policies have a negative effect on eco-innovation. However these effects are insignificant. The only exception is the three year lag variable of technological support policies which shows to be negative and statistically significant at a 10% significance level. This is an interesting observation as this is in line with hypothesis 2c. When comparing these findings with the initial results presented in Table 4 of the results section the sign of the effects are different as those results illustrate positive coefficients for the market-based environmental policies and the current and first year lag of technology support environmental policy variables. These effects are however insignificant as well.

Concerning the effects of environmental policy stringency on TFP growth, both Table 3 in Appendix D and the initial results of Table 6 of the results section show insignificant coefficients for the environmental policy stringency variable. In comparison with the initial results, the results of the effect of environmental policy stringency on TFP growth of the limited sample however does not follow the same path as the base results as the coefficients remain negative and do not turn positive over time. When distinguishing between the effects of the stringency of different environmental policies on TFP growth, the coefficients of Table 4 in Appendix D and Table 7 in the results section do mostly point in the same general direction in terms of sign and significance. One main observation is that the 1 year lagged variable of the market-based environmental policy variable lost its significance in the regression of the OECD sample compared to the original results. Lastly, based on these findings a mediating effect of eco-innovation can also be excluded for the limited sample similar to the original results. To conclude, given that the results of the regressions with a limited sample do differ from the initial results in terms of significance it can be concluded that the results are somewhat driven by the data of the non-OECD countries and the model is not robust to changes in terms of the sample.

7 Discussion and Conclusion

In recent times, the discussion about whether more stringent environmental policies are beneficial or detrimental to a country's level of eco-innovation and productivity growth has intensified. Existing literature has not been able to find a general consensus yet and country-level studies regarding these relationship have been limited. Furthermore, the effects of different forms of more stringent environmental policies on eco-innovation and the mediating role of eco-innovation in the relationship between more stringent environmental policies and productivity growth have not been examined. Hence, this research paper investigated these matters on a country level with the aim to fill these gaps in literature. To do this, four main hypotheses were developed based on the proposed theory of Porter and Van der Linde (1995). The hypotheses were tested using fixed effects regressions on a sample of 39 countries with data points from 2000 up until 2018.

The first hypothesis proposed that more stringent environmental policies have a positive effect on eco-innovation. This hypothesis is well supported by the empirical results of this research paper. The results are consistent with the findings of the empirical studies of Ahmed (2020) and Galeotti et al. (2020) who also find positive and significant effects of the same environmental policy stringency index on environmental innovation on a country level. The positive relationship can be explained by the change in costs of pollutive production factors which drives firms to engage in environmental innovation to limit pollution and the imposed costs (Lanoie et al., 2011; Martin & Scott, 2000; Porter & Van der Linde, 1995).

The second hypothesis that was proposed focuses on the effects of different more stringent environmental policy forms on eco-innovation. According to the narrow Porter hypothesis, the effect of more stringent environmental policies on eco-innovation is based on the flexibility of the environmental policy instrument (Porter & Van der Linde, 1995). This can take the form of within-flexibility and across-flexibility (Gayer & Horowitz, 2006). Hypothesis 2a and 2b propose positive effects of more stringent market-based and non-market-based environmental policies on eco-innovation, while hypothesis 2c introduces that more stringent technological support environmental policies have a negative effect on eco-innovation. This research paper finds empirical support regarding the hypothesis that more stringent non-market-based environmental policies have a positive effect on eco-innovation. However, the results of the effects of more stringent market-based and technological support environmental policies are not in line with their corresponding hypotheses as the estimates of the variables turn out to be insignificant. Hypothesis 2d proposes that the effect of more stringent market-based environmental policies is larger than those of more stringent non-market-based and technology support environmental policies. As the estimates of more stringent market-based environmental policies turn out to be insignificant, this hypothesis cannot be supported.

The proposed hypotheses were fully based on theoretical arguments as there are no previous studies who have studied the relationship between these different types of environmental policies and eco-innovation. One possible explanation for these unexpected results is the fact that the barriers of eco-innovating are very high due to the existence of the double externality problem. As aforementioned, eco-innovations, unlike traditional innovations, bring about positive spillover effects at both the innovation and diffusion stages. Firms therefore have lower incentives to engage in eco-innovations. It could be argued that unless the environmental policy is mandatory, firms will not overcome the barriers of eco-innovation as the benefits from eco-innovating cannot be appropriated. Non-market-based environmental policies are a policy form that mandates firms to pollute less while in the case of market-based and technology support environmental policies firms can decide to not engage in reducing pollution levels. Hence, the benefits of eco-innovating do not exceed the increase imposed costs of the implemented market-based and technology support environmental policies.

Hypothesis three proposes that the effect of more stringent environmental policies on productivity growth is negative on the short run and positive in the medium to long run. Contrary to the expectations, the results show that there is no significant effect of more stringent environmental policies on productivity growth. However the models that distinguish between the different types of environmental policies show a different result. On the short run more stringent market-based environmental policies have a significantly negative effect on productivity growth and on the medium to long run more stringent technological support policies have a positive and significant effect on productivity growth. It could be the case that the estimates of the models that do not distinguish between environmental policy stringency forms are insignificant as this is a composite measure of the different environmental policy forms. Distinguishing between the different types of environmental policies is therefore of importance and is recommended to be taken into consideration for future research on the relationship between more stringent environmental policies and productivity growth.

Lastly, hypothesis four concerns the mediation role of eco-innovation also referred to as the strong Porter hypothesis. In contrast to the mediating role of eco-innovation that was expected, no statistically significant mediating effect of eco-innovation on the relationship between more stringent environmental policies and productivity growth is found. As aforementioned, more stringent environmental policies do not have a significant effect on productivity growth. This may explain the insignificant mediating role of eco-innovation as the first condition of establishing the mediating role is a relationship between more stringent environmental policies and productivity growth (Barron & Kenny; 1986). For market-based and technology support environmental policies, the second condition of a mediating role is not met. The reason for this is that although these variables have a significant relationship with productivity growth, they do not have a significant effect on eco-innovation.

Another result worth mentioning is that this research paper finds that eco-innovation does not have significant effect on productivity growth. Porter and Van der Linde (1995) did insinuate that the effects of more stringent environmental policies do not always lead to a significant change in productivity. The reason for this is that eco-innovation can take different forms where some forms of eco-innovation simply lessen pollution without improving impacted products and/or processes. Based on this reasoning, the findings of this research paper could indicate that the type eco-innovations that are induced by more stringent environmental policies are not productivity enhancing.

This research paper has several limitations that should be taken into account and could provide suggestions for future research. Firstly, the dataset used in this study only consist of data from 2000 until 2018. This is a limitation as it could take time before the effects of more stringent environmental policies on eco-innovation and productivity growth become present. Therefore, estimating the effects on an even longer time frame with models including more time lags is a suggestion for further research when more data is available. Secondly, data on more developing countries, regarding the stringency of environmental policies is less available than data on developed countries. Therefore, not all countries are evenly represented in the sample. As the findings of the robustness check are not fully comparable to the initial findings, there could be significant differences between OECD and non-OECD countries when it comes to the relationship between more stringent environmental policies, eco-innovation and productivity growth. Therefore further research into this difference by means of a moderating analysis can definitely be of use when more data on non-OECD countries is available.

Lastly, a limitation that should be noted is that endogeneity problems could still arise with lagging the variables (Leszczensky & Wolbring; 2022). As aforementioned, higher levels of productivity growth can also increase the stringency of environmental policies instead of the other way around. To address these concerns, the models in this paper included lagged variables of the independent and control variables. Even though lagging the independent variable aids in addressing the strict exogeneity assumption for the current independent variable, the same assumption has to apply for the models with the lagged variables. This means that any unobserved variable in these models cannot be correlated with the error term (Bellemare et al., 2017). Consequently, the findings of this research should be interpreted with care as this limitation restricts the interpretation of a causal relationship. Future research could take this into consideration by using an instrumental variable approach.

To conclude, the weak version of the Porter hypothesis is strongly supported by the empirical findings. More stringent environmental policies have a positive effect on eco-innovation. When distinguishing between the different environmental policy forms, non-market-based environmental policies are found to have a positive significant effect on eco-innovation. In other words, the positive effect of more stringent environmental policies on eco-innovation stems from more stringent non-market-based environmental policies. The narrow Porter hypothesis is not supported as the effects of market-based environmental policies on eco-innovation are insignificant. Moreover, this study also does not find any support for the strong Porter hypothesis as eco-innovation does not seem to play a statistically significant mediating role between more stringent environmental policies and productivity growth. When it comes to the relationship between more stringent environmental policies and productivity growth this paper finds that market-based and technology support environmental policies do significantly affect productivity growth on certain time lags. Nevertheless, these effects are vanished when the effect of the composite index of more stringent environmental policies on productivity growth is considered.

The findings of this research paper can help policymakers to improve their current and future environmental policy making process. Policymakers can stimulate eco-innovation by introducing more stringent environmental policies. To do this however, the focus should lie on imposing more stringent non-market-based environmental policies. This result is especially relevant for governments that currently have less stringent non-market-based environmental policies. To increase productivity growth, the results of this research paper recommend more stringent technology support environmental policies and moving away from more stringent market-based environmental policies. Policymakers should be noted that the benefits of more stringent technology support environmental policies are however only observed over a longer time period.

Appendices

Appendix A

Table 1

List of Countries in the Sample

1. Australia
2. Austria
3. Belgium
4. Brazil
5. Canada
6. Chile
7. China
8. Czech Republic
9. Denmark
10. Estonia
11. Finland
12. France
13. Germany
14. Greece
15. Hungary
16. Iceland
17. India
18. Indonesia
19. Ireland
20. Israël
21. Italy
22. Japan
23. Korea
24. Luxembourg
25. Mexico
26. Netherlands
27. New Zealand
28. Norway
29. Poland
30. Portugal
31. Russia
32. Slovak Republic
33. Slovenia
34. South Africa
35. Spain
36. Sweden
37. Switzerland
38. Turkey
39. United Kingdom

Appendix B

Table 1.1

Variance Inflation Factors (EPS Indicator)

	VIF	1/VIF
EPS	1.546	0.647
R&D Expenditure	2.003	0.499
Patent Stock	1.595	0.627
Renewable Energy Consumption	1.449	0.690
Industry Value Added	1.120	0.892
Trade Openness	1.686	0.593
FDI	1.202	0.832
Human Capital	1.951	0.512

Table 1.2

Variance Inflation Factors (Subindices EPS)

	VIF	1/VIF
EPS: Market-based	1.688	0.592
EPS: Non-market-based	2.101	0.476
EPS: Technology Support	1.832	0.546
R&D Expenditure	2.041	0.490
Patent Stock	1.684	0.594
Renewable Energy Consumption	1.518	0.659
Industry Value Added	1.170	0.854
Trade Openness	1.751	0.571
FDI	1.204	0.831
Human Capital	1.980	0.505

Appendix C

Table 1

Fixed Effects Regression Results of the Effect of Eco-innovation on Productivity Growth

	TFP Growth			
	(1)	(2)	(3)	(4)
Ln Eco-innovation	-0.335			
	(0.495)			
Ln Eco-innovation (-1)		-0.251		
		(0.472)		
Ln Eco-innovation (-2)			-0.303	
			(0.413)	
Ln Eco-innovation (-3)				0.361
				(0.544)
R&D Expenditures (-1)	0.145	0.135	0.165	-0.171
	(0.454)	(0.551)	(0.557)	(0.637)
Patent Stock (-1)	0.000	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Renewable Energy Consumption (-1)	0.048	0.051	0.049	0.064
	(0.044)	(0.041)	(0.043)	(0.045)
Industry Value Added (-1)	-0.348***	-0.349***	-0.350***	-0.343***
	(0.118)	(0.117)	(0.117)	(0.118)
Trade Openness (-1)	0.042***	0.042***	0.043***	0.043***
	(0.015)	(0.015)	(0.015)	(0.015)
FDI (-1)	0.029**	0.030**	0.029**	0.029**
	(0.012)	(0.011)	(0.011)	(0.012)
Human Capital (-1)	-1.815	-1.749	-1.707	-2.379
	(1.947)	(1.974)	(2.064)	(2.062)
Constant	9.919	9.305	9.396	9.106
	(7.845)	(7.486)	(7.444)	(7.759)
N	573	573	573	573
No. of countries	39	39	39	39
R^2	0.222	0.221	0.222	0.222

Note. This is a level-log regression. Standard errors in parentheses. * indicates $p < 0.10$. ** indicates $p < 0.05$. *** indicates $p < 0.01$.

Appendix D

Table 1

Fixed Effects Regression Results of the Effect of Environmental Policy Stringency on Eco-patent Applications - OECD Sample

	Eco-innovation (Natural logarithm)			
	(1)	(2)	(3)	(4)
EPS	0.078 (0.065)			
EPS (-1)		0.055 (0.070)		
EPS (-2)			0.043 (0.063)	
EPS (-3)				0.070 (0.074)
R&D Expenditures (-1)	0.341*** (0.082)	0.335*** (0.080)	0.328*** (0.081)	0.322*** (0.082)
Patent Stock (-1)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
Renewable Energy Consumption (-1)	-0.005 (0.011)	-0.006 (0.011)	-0.006 (0.012)	-0.005 (0.012)
Industry Value Added (-1)	0.007 (0.017)	0.007 (0.017)	0.007 (0.017)	0.007 (0.017)
Trade Openness (-1)	-0.004 (0.003)	-0.004 (0.003)	-0.004 (0.003)	-0.004 (0.003)
FDI (-1)	-0.000 (0.001)	-0.000 (0.001)	-0.000 (0.001)	-0.000 (0.001)
Human Capital (-1)	1.623** (0.732)	1.638** (0.743)	1.661** (0.743)	1.658** (0.729)
Constant	-1.730 (2.264)	-1.699 (2.295)	-1.719 (2.312)	-1.730 (2.292)
N	474	474	474	474
No. of countries	32	32	32	32
R^2	0.609	0.608	0.607	0.609

Note. Standard errors in parentheses. * indicates $p < 0.10$. ** indicates $p < 0.05$. *** indicates $p < 0.01$.

Table 2

Fixed Effects Regression Results of the Effect of Market-based, Non-market-based and Technology Support Environmental Policy Stringency on Eco-Innovation - OECD Sample

	Eco-innovation (Natural logarithm)			
	(1)	(2)	(3)	(4)
EPS: Market-based	-0.043 (0.049)			
EPS: Non-market-based	0.087** (0.032)			
EPS: Technology Support	-0.004 (0.022)			
EPS: Market-based (-1)		-0.078 (0.054)		
EPS: Non-market-based (-1)		0.062* (0.035)		
EPS: Technology Support (-1)		-0.003 (0.026)		
EPS: Market-based (-2)			-0.040 (0.060)	
EPS: Non-market-based (-2)			0.068* (0.038)	
EPS: Technology Support (-2)			-0.022 (0.024)	
EPS: Market-based (-3)				0.002 (0.070)
EPS: Non-market-based (-3)				0.094** (0.042)
EPS: Technology Support (-3)				-0.037* (0.019)
R&D Expenditures (-1)	0.302*** (0.086)	0.307*** (0.084)	0.298*** (0.086)	0.296*** (0.087)
Patent Stock (-1)	0.000 (0.000)	0.000 (0.000)	0.000* (0.000)	0.000** (0.000)
Renewable Energy Consumption (-1)	-0.002 (0.010)	-0.002 (0.011)	-0.001 (0.011)	-0.000 (0.010)
Industry Value Added (-1)	0.005 (0.015)	0.007 (0.015)	0.006 (0.015)	0.005 (0.015)
Trade Openness (-1)	-0.004 (0.003)	-0.004 (0.003)	-0.004 (0.003)	-0.003 (0.003)
FDI (-1)	-0.000 (0.001)	-0.000 (0.001)	-0.000 (0.001)	-0.000 (0.001)

Human Capital (-1)	1.652**	1.684**	1.758**	1.786**
	(0.689)	(0.713)	(0.697)	(0.661)
Constant	-1.840	-1.855	-2.097	-2.287
	(2.127)	(2.191)	(2.168)	(2.082)
N	474	474	474	474
No. of countries	32	32	32	32
R^2	0.620	0.617	0.617	0.628

Note. Standard errors in parentheses. * indicates $p < 0.10$. ** indicates $p < 0.05$. *** indicates $p < 0.01$.

Table 3

Fixed Effects Regression Results of the Effect of Environmental Policy Stringency on Productivity Growth - OECD Sample

	TFP Growth			
	(1)	(2)	(3)	(4)
EPS	-0.237			
	(0.522)			
EPS (-1)		-0.107		
		(0.596)		
EPS (-2)			-0.501	
			(0.409)	
EPS (-3)				-0.376
				(0.516)
R&D Expenditures (-1)	-0.209	-0.179	-0.186	-0.141
	(0.492)	(0.501)	(0.486)	(0.488)
Patent Stock (-1)	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Renewable Energy Consumption (-1)	-0.093	-0.092	-0.097	-0.096
	(0.0658)	(0.066)	(0.067)	(0.066)
Industry Value Added (-1)	-0.488***	-0.487***	-0.486***	-0.487***
	(0.103)	(0.102)	(0.103)	(0.103)
Trade Openness (-1)	0.040***	0.040***	0.040***	0.041***
	(0.012)	(0.013)	(0.013)	(0.013)
FDI (-1)	0.030***	0.029***	0.029***	0.030***
	(0.010)	(0.010)	(0.010)	(0.010)
Human Capital (-1)	-1.690	-1.790	-1.579	-1.728
	(2.387)	(2.244)	(2.324)	(2.314)
Constant	14.570*	14.510*	14.420*	14.560*
	(7.318)	(7.188)	(7.469)	(7.360)
N	474	474	474	474
No. of countries	32	32	32	32
R^2	0.255	0.255	0.257	0.256

Note. Standard errors in parentheses. * indicates $p < 0.10$. ** indicates $p < 0.05$. *** indicates $p < 0.01$.

Table 4

Fixed Effects Regression Results of the Effect of Market-based, Non-market-based and Technology Support Environmental Policy Stringency on Productivity Growth - OECD Sample

	TFP Growth			
	(1)	(2)	(3)	(4)
EPS: Market-based	-0.668 (0.531)			
EPS: Non-market-based	0.027 (0.356)			
EPS: Technology Support	-0.050 (0.234)			
EPS: Market-based (-1)		-0.764 (0.547)		
EPS: Non-market-based (-1)		-0.046 (0.360)		
EPS: Technology Support (-1)		0.083 (0.218)		
EPS: Market-based (-2)			-1.356* (0.712)	
EPS: Non-market-based (-2)			-0.257 (0.254)	
EPS: Technology Support (-2)			0.093 (0.201)	
EPS: Market-based (-3)				-0.504 (0.563)
EPS: Non-market-based (-3)				-0.382 (0.339)
EPS: Technology Support (-3)				0.169 (0.154)
R&D Expenditures (-1)	-0.215 (0.435)	-0.082 (0.494)	0.035 (0.524)	0.007 (0.477)
Patent Stock (-1)	0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
Renewable Energy Consumption (-1)	-0.082 (0.066)	-0.079 (0.068)	-0.075 (0.072)	-0.103 (0.074)
Industry Value Added (-1)	-0.485*** (0.107)	-0.477*** (0.098)	-0.470*** (0.095)	-0.479*** (0.102)
Trade Openness (-1)	0.038*** (0.012)	0.037*** (0.013)	0.0323** (0.012)	0.036** (0.013)
FDI (-1)	0.029*** (0.010)	0.027** (0.010)	0.027*** (0.009)	0.030*** (0.009)

Human Capital (-1)	-1.692	-1.778	-1.435	-2.058
	(2.367)	(2.207)	(2.385)	(2.474)
Constant	14.680**	14.720**	14.470*	16.400**
	(7.160)	(6.957)	(7.412)	(7.768)
N	474	474	474	474
No. of countries	32	32	32	32
R^2	0.258	0.259	0.269	0.262

Note. Standard errors in parentheses. * indicates $p < 0.10$. ** indicates $p < 0.05$. *** indicates $p < 0.01$.

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