Louvain School of Management

Testing the Strong Porter Hypothesis in the European Automotive Sector

Environmental Policy Stringency, Innovation, and Competitiveness in Germany, France, and Italy

Author: Celine Kasteel
Supervisor: Per Joakim Agrell
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Abstract

This present thesis examines whether stricter environmental regulations stimulate innovation and enhance competitiveness in the European automotive industry, focusing on Germany, France, and Italy between 1996 and 2020. Building on the strong version of the Porter Hypothesis, the analysis explores whether environmental policy stringency leads to increased research and development (R&D) investment, and whether this innovation subsequently improves productivity, measured by total factor productivity (TFP). Using a fixed-effects panel regression with country and year specific controls, the study combines data from the OECD Environmental Policy Stringency Index and EU KLEMS.

The results show weak and statistically insignificant relationships between policy stringency and innovation, as well as between innovation and productivity. Country-level differences reveal that Germany and France, despite higher R&D spending and stricter policies, did not experience measurable productivity gains, while Italy's outcomes were comparatively less negative but still inconclusive. These findings align with existing literature questioning the validity of the strong Porter Hypothesis, suggesting that the link between regulation, innovation, and competitiveness is highly context-dependent and shaped by policy design and industrial structure. The thesis emphasizes the need for complementary strategies beyond regulatory pressure to achieve both environmental and competitiveness goals in the automotive sector.

Keywords: Porter Hypothesis, Environmental Policy Stringency, Automotive Industry, Competitiveness, Innovation

UNIVERSITÉ CATHOLIQUE DE LOUVAIN
Louvain School of Management
Place des Doyens, 1 bte L2.01.01, 1348 Louvain-la-Neuve
Boulevard Emile Devreux 6, 6000 Charleroi, Belgique
Chaussée de Binche 151, 7000 Mons, Belgique
www.uclouvain.be/lsm

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1. Introduction

1.1 Background

In recent years, the European automotive sector has found itself at the center of the continent's transition towards more sustainable industry practices. A defining moment in this shift was the 2015 Dieselgate scandal, in which a major car manufacturer was found to have manipulated emissions tests (Lechowski et al., 2023). The scandal not only undermined consumer confidence but also triggered a wave of regulatory responses, pushing governments to strengthen environmental standards and emissions controls (Krzywdzinski et al., 2022). This event became a turning point, placing environmental regulation and innovation at the heart of industrial policy debates.

Since then, the European Union has launched initiatives such as the Green Deal and the Fit-for-55 package, aiming to drastically reduce greenhouse gas emissions by 2030 and achieve climate neutrality by 2050. These initiatives, particularly their impact on the automotive industry, have brought up a key question of whether stricter environmental regulation could serve as an incentive for innovation and improve competitiveness in a sector under increasing global pressure.

The automotive industry is one of Europe's largest economic sectors, employing 13.8 million workers and accounting for 6.1% of total EU employment, as well as being the sector with the largest private investment in R&D (European Commission, 2022). At the same time, it is under increasing pressure from multiple directions: rising regulatory demands, a technological transition toward electric mobility and digitalization, and growing competition from non-European markets, particularly China. European carmakers are now expected to reduce emissions as well as invest in innovation, while remaining competitive. Understanding whether stricter environmental policies help or hinder these efforts is essential for both policymakers and industry actors.

1.2 Research Question

This thesis focuses on that intersection: it examines whether increased environmental policy stringency leads to more innovation (measured through R&D investment), and whether this innovation translates into improved competitiveness (measured through total factor productivity, or TFP) in the automotive industries of Germany, France, and Italy. For that reason, this thesis will aim to answer the following research question: *"Can stricter environmental regulation increase innovation and competitiveness in Europe's automotive sector? A test of the strong Porter Hypothesis in Germany, France, and Italy."*

To explore this, the thesis builds on the theoretical framework of the Porter Hypothesis. Proposed by Porter and Van der Linde in 1995, the hypothesis challenged the traditional view that environmental regulation always imposes costs on firms. Instead, it argued that well-designed regulations could actually encourage firms to innovate and improve their performance. The strong version of the Porter Hypothesis goes even further, claiming that these innovations can not only offset the costs of compliance but even increase competitiveness (Ambec et al., 2013).

This thesis tests that idea empirically in the specific context of Europe's car industry. The first hypothesis is that stricter environmental policies lead to more R&D investment in the sector. The second hypothesis is that this increased innovation, in turn, improves productivity and competitiveness. Together, these two hypotheses form the chain that underlies the strong Porter Hypothesis.

1.3 Limitations

However, it is important to acknowledge the scope of this research and its several subsequent limitations. The analysis is conducted at the industry level and covers only three countries: Germany, France, and Italy. Focusing on a single industry allows for depth and contextual understanding, but it also means the sample size, regarding number of observations, is relatively small, which in turn limits the statistical power and the reliability of the tests. Moreover, many of the statistical results are not significant in relation to the hypotheses.

The findings do not show strong or consistent evidence that environmental policy stringency leads to increased innovation, nor that innovation leads to productivity gains. Aggregate indicators like R&D expenditure and TFP provide an overview but fail to offer qualitative differences in the type and effectiveness of innovation. Moreover, the time period may still be too short to observe the full effects of green investments, especially if the benefits of technologies such as electric vehicles take longer to materialize.

While this does not disprove the logic of the Porter Hypothesis, it suggests that its effects are not easily observed in this setting. This is in line with existing research, which often finds that the impact of environmental regulation on innovation and competitiveness is highly context-dependent (Cohen & Tubb, 2018). By being transparent about these limitations, the thesis sets realistic expectations about the insights that can be drawn, and it highlights areas where further research or data might be needed to fully capture the effects in question.

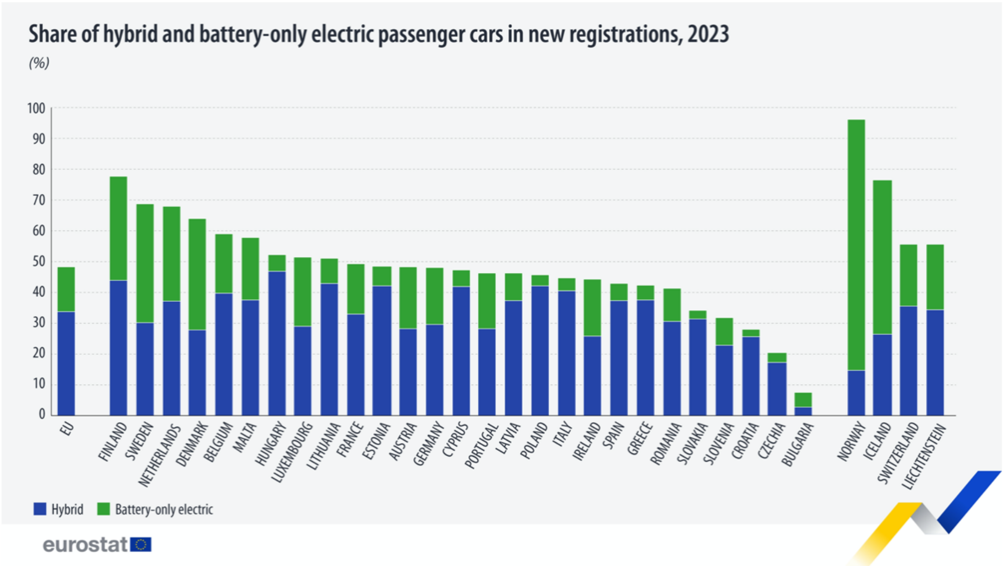
1.4 Outline

The rest of this thesis is structured as follows. The next chapter provides background on the policy context in the EU and in the three selected countries, describing key initiatives and national approaches to environmental regulation in the automotive sector. The third chapter presents the literature review, focusing on the theoretical and empirical debates around environmental policy, innovation, and competitiveness, with particular attention to the Porter Hypothesis. The fourth chapter outlines the methodology and data used for the analysis, including the variables selected and the fixed-effects panel regression approach. Chapter five presents the empirical results of the study, both at the overall and country-specific levels. Finally, the discussion and conclusion summarize the findings, reflect on their implications for different stakeholders, and offer suggestions for future research.

Through this structure, the thesis aims to evaluate whether tougher environmental regulation has indeed promoted innovation and improved competitiveness in the European car industry, or whether the relationship is more complex than theory might suggest.

2. Automotive Policy and Outcomes in Europe

Figure 1: Share of hybrid and battery-only electric passenger cars in new registrations, 2023.



Note. Adapted from Eurostat (2024)

2.1 Germany

Environmental policy has become a central driver of industrial transformation in Europe, particularly within the automotive sector. In Germany, this shift is, amongst others, seen through the *Energiewende*, the country's long-term strategy to transition towards a low-carbon economy (Unnerstall, 2017). Originally focused on renewable energy deployment, the *Energiewende* has gradually expanded to include transportation and industry, setting ambitious targets, including a 65% reduction in energy sector emissions by 2030 and climate neutrality by 2045 (Unnerstall, 2017). This transition has triggered structural changes within the economy, creating both winners, such as firms in the renewable and electric mobility sectors, and losers, notably those dependent on conventional power and combustion technology (Unnerstall, 2017).

The German automotive industry, historically a global leader, has been significantly affected by these shifts. Although manufacturers initially focused on optimizing internal combustion engines, the Dieselgate scandal in 2015 catalyzed a switch towards electrification, supported by substantial government investment in EV subsidies, charging infrastructure, and R&D (Krzywdzinski et al., 2022; Lechowski et al., 2023). Measures such as the Clean Air Plan, the National Electric Mobility Platform, and the Automotive Industry Future Fund have helped pushed the sector toward compliance with increasingly stringent EU emissions standards (Krzywdzinski et al., 2022; Ragonnaud 2024). This had led to battery-electric and hybrid vehicles making up nearly 48% of new car registrations in Germany in 2023 (see Figure 1), placing it mid-range among EU countries. The figure also shows the fact that Germany is behind many other countries in EV adoption per capita.

Indeed, the transition has not been without challenges. Smil (2024) argued that pushing the green transition is premature, if labour is not able to follow the same trends: '*Germany, thanks to its Energiewende (energy transition) is the EU's leader in the pursuit of greenness and it is already affected: in 2023 the country lacked about 216,000 skilled workers to expand solar and wind power, and the now mandatory installation of heat pumps needs another 80,000 technicians (p. 23).* In parallel, the auto sector is at risk of falling behind in battery innovation and EV scale-up, especially compared to China's aggressive, centrally coordinated strategy (Draghi, 2024). As the EU prepares to phase out internal combustion engines by 2035, German automakers face increasing pressure to accelerate innovation to remain competitive.

2.2 France

France's automotive sector has long been affected by industrial fragmentation and deindustrialization (Aussilloux et al., 2020). Compared to Germany, France was slower to establish a cohesive industrial policy for sustainable transport. High taxes and structural decline weakened its competitiveness, and today, the country's automotive output accounts for less than one-sixth of Germany's (Aussilloux et al., 2020). Nonetheless, recent partnerships, such as with Germany on battery production, suggest a growing alignment with EU decarbonization goals, and real desire to compete with the Chinese EV market (Aussilloux et al., 2020). In 2023, France's share of new EV and hybrid registrations reached approximately 50% (Eurostat, 2023), similar to Germany.

As mentioned before, France's automotive industry has long struggled with structural decline and deindustrialization. Since the mid-2000s, vehicle production in France dropped from 3.7 million to 1.7 million at its lowest point, recovering only partially in the years that followed (Pardi, 2019). This decline was driven by the relocation of production to Eastern Europe and Turkey and intensified competition from German brands. Despite this, France responded to the COVID-19 crisis and EU Green Deal with strong financial support: €5 billion in loans, €850 million in battery-related investments, and €150 million in R&D through its 4th Investment Programme for the Future (PIA4) (IEA, 2025).

Still, compared to Germany, France's efforts have been slower and more fragmented. High tax burdens on French manufacturers and consumers have undermined domestic demand, while employment in the sector continues to decline despite modest recovery in production volumes (Aussilloux et al., 2020; Pardi, 2019). Efforts to relaunch national platforms for industrial coordination, such as the Plateforme de la Filière Automobile (PFA), have repeatedly been lacking due to weak consensus among stakeholders and inconsistent state support (Pardi, 2019). As China strengthens its position in global EV production, France must improve policy coherence and scale investment to remain competitive.

2.3 Italy

Italy presents a structurally distinct case within the broader European automotive landscape, shaped by its historically centralized industrial model and a supply chain dominated by SMEs (Calabrese, 2020). The sector has long been centered around Fiat Chrysler Automobiles, which has maintained an important role in coordinating one of Europe's largest and most SME-dependent supply networks. However, this system has faced continued stagnation, with vehicle production declining by over 50% from 2007 to 2013, and continuing to lag in the global shift toward electric mobility (Calabrese, 2020). In 2023, only around 5% of new vehicles registered in Italy in 2023 were fully electric, and around 40% hybrid (Eurostat, 2023; see Figure 1). This places Italy at the bottom among EU member states in EV adoption. Recent consumer perception data also show that Italian buyers remain skeptical toward EVs due to, amongst others, battery range and costs (McKinsey, 2023). The Italian government has articulated climate ambitions through its National Energy and Climate Plan (NECP), which includes a target of six million electric vehicles by 2030. Yet, compared to Germany and France, Italy lacks a clear state-led industrial strategy that aligns environmental targets with competitiveness-enhancing measures (Calabrese, 2020; European Commission, 2024).

The broader industrial design of Italy also shows signs of structural vulnerability. Although the automotive sector employs over 340,000 people and generates significant added value, the shift toward electric mobility has not been matched with proportionate industrial policy (Crestia et al., 2024). As recent projections have shown, Italy risks suffering severe losses in output and employment by 2030 if it fails to realign its production capacity with the demands of the green transition (Crestia et al., 2024). While there have been steps to support renewable energy and fuel diversification, long-term policy support for the reduction of oil consumption of the automotive sector has been weak, paired with a lack of EV infrastructure (International Energy Agency, 2023; Raimondi & Noussan, 2024). For instance, the fiscal system further undermines market competitiveness: company cars, which represent a key growth segment in other EU markets, are significantly penalized in Italy through unfavorable tax deductions compared to other member states (20% in Italy, up to 100% in other EU countries) (Calabrese, 2020). This has weakened domestic demand and constrained the sector's ability to modernize.

In sum, without a more coordinated strategy to scale charging infrastructure, retrain labor, and support innovation, Italy risks falling further behind. Structural weaknesses and fragmented policies continue to undermine its transition to low-emission mobility. (European Commission, 2024; Raimondi & Noussan, 2024).

2.4 European Union

At the EU level, the regulatory landscape for the automotive sector has become increasingly stringent, particularly through the European Green Deal and the *Fit-for-55* package, which aim to reduce greenhouse gas emissions by at least 55% by 2030, phase out internal combustion engine (ICE) vehicles, and accelerate the shift toward low-carbon innovation. While these initiatives set ambitious targets, the EU has had trouble matching its rules with what its industry can do, creating uncertainty and compliance issues for the stakeholders (Claeys et al., 2019). Though harmful emissions from each car have gone down with Euro 1–6 standards, carbon dioxide emissions from road transport went up by more than 20% between 1990 and 2019. This is mostly because there are more cars on the road and not many people are using other ways to travel. (Draghi, 2024).

The EU’s lack of coherent support for supply chain transformation has left its automotive sector vulnerable to external pressures. China, in contrast, has rapidly developed a centrally coordinated EV strategy, dominating the global value chain through early investment, early investments and strong control over production and key resources. (Draghi, 2024; Ragonnaud, 2024). In 2023, China accounted for 60% of all new EV registrations worldwide, enabling its producers to benefit from large economies of scale, as well as lower labor costs (Draghi, 2024).

As the EU pushes for a faster adoption of electric vehicles, it risks lagging behind. The Draghi Report (2024) emphasizes this concern, warning that without rapid and unified action from member states to strengthen supply chains and industrial capacity, more than 10% of EU-based automotive production could be lost in the coming years. This underscores the growing urgency for the EU to not only set ambitious climate targets but also to implement coordinated and innovation-based industrial policies that increase the global competitiveness of its automotive sector.

Finally, while much of this policy review has focused on automotive regulation, the broader intent of the EU Green Deal is to create spillover effects across sectors. If the EU's Green Deal proves effective in scaling competitiveness and innovation in automotive, this model could support similar transitions in heavy industry, aviation, and construction. Conversely, if the EV shift fails to be competitive and most importantly, coordinated, the broader regulatory effort may not be enough (Tagliapietra & Veugelers, 2020).

3. Literature Review

When it comes to the question of the impact of environmental regulation on a certain industry or country's competitiveness, literature tends to offer a heterogenous answer. Traditionally, most economists believed that environmental regulations, such as those aimed at reducing pollution, would inevitably limit firms' choices and therefore lower their profits. The reasoning was that if decreasing pollution were profitable, firms focused on maximizing profit would already be doing it (Ambec & Lanoie, 2008; Ambec et al., 2013). If markets are optimal, companies will reach an equilibrium in the use of scarce resources, and environmental regulations would divert them from their profit optimization goal (Ambec & Lanoie, 2008). This is a belief that is still held firmly today by some companies and some of the greater public, but is eroding due to new regulations being put into place by, amongst others, the EU.

In the mid-90s, Porter and Van der Linde (1995) challenged this conventional view. They argued that environmentally-oriented regulations could boost competitiveness and open up market opportunities for the firms that implement them, as well as just overall produce long-term benefits (Fan & Iqbal, 2022; Porter & Van der Linde, 1995). This was based on the premise that the costs of reducing pollution can be partially or fully balanced out by benefits achieved elsewhere. The argument is that cutting pollution does not always lead to improved economic performance, but the costs involved can be partially or fully recovered through benefits in other areas (Ambec et al., 2013). Their analysis of environmental policies and competitiveness gave birth to the Porter Hypothesis, which was later formally divided by Ambec et al. (2013) into three different branches to clarify, interpret, and empirically test the hypothesis. Firstly, the weak version, which states that environmental regulations trigger innovation, but that the opportunity costs of these innovations might be greater than the direct benefits they provide to the firm. The second version, the strong Porter Hypothesis, claims that innovations due to environmental policies lead to a greater productivity of firms. Lastly, the narrow version implies that the right types of policies, i.e. flexible and market-based, are more likely to produce gains in productivity (Albrizio et al., 2017; Ambec et al., 2013; Cohen & Tubb, 2018). The latter became especially relevant in literature, as Ambec et al. (2011) attempted to clarify the following important point: '*There is much confusion in the literature about what the Porter Hypothesis actually says. As we note above, it does not say that all regulation leads to innovation - only that well-designed regulations do*' (p. 4). This nuanced understanding of the Porter Hypothesis has since become a foundation for ongoing research into how the design and implementation of environmental regulations can influence both innovation and economic performance across industries. However, the article by Porter and Van der Linde (1995) gained criticism. For instance, Palmer et al. (1995) questioned the idea that environmental regulations can boost firm performance at no cost. They argued that, in most cases, complying with stricter standards does involve real costs, and the benefits from innovation are not guaranteed to fully offset them. Their work challenged the optimistic view of the Porter Hypothesis, suggesting that a careful cost-benefit analysis is still necessary. The relationship between environmental regulation and green innovation is influenced by the type of country (developed or developing) and the scale of analysis (such as firm, city, province, or national level) (Zhang et al., 2024).

When it comes to the literature regarding the PH, the results tend to present heterogeneous results, often depending on the method. Cohen and Tubb (2018) conducted a meta-analysis on 103 different publications, and they found that, though studies tend to find a positive relation between environmental policy and innovation, the size of this correlation varied across these studies (Cohen & Tubb, 2018). They also found that the type of study matters: a negative relationship was more likely to be found at a firm/industry level, while at a state/country level, the results were more likely to bring positive correlation (Cohen & Tubb, 2018). The negative impact of environmental policy on industries was further analyzed by Benatti et al. (2024) using the OECD Environmental Policy Stringency Index. They found that a higher stringency negatively affects the total factor productivity (TFP), and that high-polluting firms are more affected than their low-polluting peers, therefore leading the authors to reject the strong PH (Ambec & Lanoie, 2008; Benatti et al., 2024, Rubashkina et al., 2015). However, in the context of the narrow PH, they argue that different types of policies have different impacts; non-market based policies are more detrimental than market-based policies. This was further shown by Abrizio et al. (2017), who found that while the aggregate impact is negative, market based instruments have a stronger positive effect in the short term compared to non-market based instruments. In the same way, flexible regulations tend to have a higher chance of showing significant and positive results than ‘command-and-control’ regulations (Abrizio et al., 2017; Cohen & Tubb, 2018; Zhang et al., 2024). Other factors such as a higher patenting propensity and equity ratio mitigate the negative effects of environmental policies (Benatti et al., 2024).

The divisions in literature also stem from the ability to pinpoint the origins of innovation; while Green (2005) argues that environmental regulation is the major driver for innovation, a study conducted in 2007 by Frondel et al. (2007) on 3100 firms across 7 OECD countries, finds that cost savings present a more important driver for innovation in the green sector. Nevertheless, R&D has been found by some authors to be positively correlated with environmental regulation, implying a validation of the strong PH (Fan & Iqbal, 2022; Triebswetter & Wackerbauer, 2008; Ambec & Lanoie, 2008). Studies revealed that environmental regulations can drive domestic firms to innovate, boosting efficiency and reducing pollution. By integrating environmental goals into product development, firms gain competitive advantages such as cost savings and stronger market positions (Triebswetter & Wackerbauer, 2008).

The way 'competitiveness' is measured also varies across studies. Fan and Iqbal (2022) assess automotive industry competitiveness in 14 Asian countries using a modified Revealed Comparative Advantage index, linking trade performance to other factors such as GDP, tariffs, and carbon emissions. Benatti et al. (2024) measure competitiveness through firm-level productivity, examining how different types of environmental regulation affect Total Factor Productivity (TFP) and labor productivity in 6 euro area countries. Their findings suggest that the impact of regulation varies by policy type and firm characteristics, with technology-support policies offering the most potential for productivity gains. Rubashkina et al. (2014) also use TFP as a proxy for sectoral competitiveness, using amongst others EU KLEMS data to capture productivity growth. While their approach offers detailed insight into efficiency and technological change, it is also limited by data availability. Together, these studies demonstrate that competitiveness can be assessed through trade performance or productivity, and that its relationship with environmental regulation is context-dependent and shaped by the method of measurement, as was revealed in other aforementioned studies (Cohen & Tubb, 2018).

The heterogeneity of the results regarding the PH also stems from the variety of methods used to assess the relationship between environmental regulation, innovation, and competitiveness. One study adopts a case study approach (Triebswetter & Wackerbauer, 2008), collecting primary data due to the lack of existing information on environmental product innovation. By comparing firm-level supply-side characteristics, it evaluates the competitiveness effects of innovation driven by regulatory pressure versus voluntary innovation. In contrast, another study uses panel local projections over a five-year horizon to estimate the impact of environmental regulation on productivity (Benatti et al., 2024). It investigates the difference between high- and low-polluting firms, and finds different effects on productivity growth depending on emission intensity. A third paper conducts a cross-country panel analysis across

OECD nations, using an index of environmental policy stringency developed by the OECD (Albrizio et al., 2017). The authors aim to understand both short-term and firm-level dynamics in response to policy tightening. Lastly, another study investigates the weak and strong versions of the Porter Hypothesis in 17 European manufacturing sectors (Rubashkina et al., 2015), focusing on both innovation and productivity as outcome variables. It uses pollution abatement and control expenditures (PACE) as a proxy for regulatory pressure and addresses potential endogeneity through an instrumental variable estimation strategy. Together, these methodologies reflect the diversity of approaches used to evaluate environmental regulation's impact on competitiveness, from firm-level case studies to large-scale econometric models. However, it is important to bear in mind that, as mentioned earlier, both the method and unit of analysis vary significantly in results. To go back to Cohen & Tubb's (2018) meta-analysis on literature pertaining to the PH, they found that the 'statistically insignificant' category remains the biggest one in terms of results, showing the ongoing debate in verifying the validity of the Porter Hypothesis. This is also something that was found by De Santis et al. (2020), who argued that the empirical evidence on the cross-country analysis remains inconclusive.

While a growing body of literature has explored the relationship between environmental regulation, innovation, and competitiveness, this thesis contributes to the field in several important ways. First, most empirical studies test the Porter Hypothesis either at the firm level or using broad cross-country samples across all sectors, often overlooking sector-specific dynamics. By focusing specifically on the European automotive industry, which, beyond being a big polluter, is a sector undergoing rapid structural change, this research offers an analysis that captures the importance of right policies on maintaining competitiveness. Second, while prior studies (e.g., Albrizio et al., 2017; Rubashkina et al., 2015; Benatti et al., 2024) have used the OECD Environmental Policy Stringency Index (EPSI) to assess aggregate trends, few have examined how changes in EPSI relate to R&D investment and productivity at the industry level across individual EU member states. This research makes contributions by examining a panel dataset from EU KLEMS that includes country-specific indicators. It tests the innovation and productivity paths of the strong Porter Hypothesis in Germany, France, and Italy. Lastly, by combining qualitative policy analysis with econometric modeling, this study gives a more in-depth understanding of how environmental rules impact industrial competitiveness, which is an area that needs more work in current research.

4. Model

This thesis adopts a quantitative strategy to assess the relationship between environmental policy stringency, innovation, and productivity in the European automotive sector. In line with the strong Porter Hypothesis, the central idea is that stricter environmental regulation can stimulate innovation, which in turn can enhance competitiveness (Porter & Van der Linde, 1995). The analysis focuses specifically on the automotive industry in three European countries: Germany, France, and Italy. These countries are major players in the European automotive market and allow for a variation in answers and reaction to environmental stringency and innovation outcomes over time. The chosen sample ranges from 1996 to 2020, as will the analysis. In order to answer the research question, the following hypotheses will be assessed through multiple regressions conducted on STATA. Those hypotheses were formulated based on previous literature, and will aim to answer the strong PH.

4.1 Hypotheses

Hypothesis A

H0a: Stricter environmental policy stringency has no effect on innovation investment in the automotive industry.

H1a: Stricter environmental policy stringency is, on average, associated with an increase in innovation investment in the automotive industry.

This hypothesis tests the first step of the strong PH. The idea is that when environmental policies become more stringent, firms are incentivized to invest in cleaner technologies, here proxied through R&D.

Hypothesis B

H0b: Higher innovation investment has no effect on productivity in the automotive industry.

H1b: Higher innovation investment is, on average, associated with an increase in productivity in the automotive industry.

The second hypothesis tests whether innovation translates into improved competitiveness. Productivity, measured through total factor productivity (TFP) or labour productivity, serves as a proxy for competitiveness. If the strong Porter Hypothesis holds, increased innovation should raise productivity.

As for Albrizio et al. (2017) and Rubashkina et al. (2015), a fixed-effects panel regression model will be used in order to answer the hypotheses. This method controls for unobserved, time-invariant country-specific characteristics that could otherwise bias the estimated relationship between environmental policy stringency and innovation or productivity (Mustafa, 2023). These include institutional features, regulatory environments, or structural economic differences across countries that do not change significantly over time but may influence both regulation and performance outcomes.

In addition, the model includes year fixed effects to control for time-specific shocks or trends that affect all countries simultaneously. This includes macroeconomic events such as the 2008 financial crisis or the Dieselgate scandal. Including these fixed effects ensures that the estimated relationship is driven by within-country, over-time variation, isolating the impact of environmental policy changes from broader trends.

Hypothesis C

H0c: The effect of environmental policy stringency on innovation investment does not differ significantly between Germany, France, and Italy.

H1c: The effect of environmental policy stringency on innovation investment differs significantly across Germany, France, and Italy.

Hypothesis D

H0d: The relationship between innovation investment and productivity in the automotive industry does not differ significantly between Germany, France, and Italy.

H1d: The relationship between innovation investment and productivity in the automotive industry differs significantly across Germany, France, and Italy

Lastly, to explore potential differences in the relationship between environmental policy stringency and innovation across countries, this thesis further incorporates country-level variation into the model. This is done by including additional variables for country-specific environmental policy stringency, which represent the stringency scores for France and Italy, respectively. Germany serves as the reference category. By including these country-specific EPSI variables alongside the overall index, the model captures the effects of environmental policy stringency on innovation across Germany, France, and Italy within a fixed-effects framework. While this approach does not rely on separate regressions per country, as the sample size does not allow it, it gives an estimation of coefficients that approximate how each country's innovation investment responds to changes in policy stringency, as well as competitiveness. This method ensures comparability while preserving the fixed-effects structure.

4.2 Regressions

Regressions 1 & 2 will be aimed at testing hypotheses A & B respectively, followed by regressions 3 & 4 for the country specific analysis (hypotheses C & D). The first regression is expressed as follows:

$$ln(innovation) = \beta_0 + \beta_1 EPSI_{it} + \beta_n Controls_{it} + \varepsilon_{it} \quad (1)$$

Where:

- Ln(innovation): Innovation was transformed into a natural logarthim, because R&D expenditure (measured in millions of currency units) is on a much larger scale than the EPS index (0 to 6),
- $EPSI_{it}$ is the OECD Environmental Policy Stringency Index for a country in year i at time t,
- $Controls_{it}$ represents a certain set of control variables, which control for unobserved, time-invariant country-specific heterogeneity (fixed effects),
- ε_{it} represents the error term.

In this regression, sets of control variables have been progressively added in order to offer nuance to the analysis. An important limitation of this research is the potential presence of an omitted variable bias, which could result in biased results. However, by adding the control variables, the probability of having an omitted explanatory variable is minimised. The control variables are explained in the following paragraph.

As for Albrizio et al. (2014) in their analysis of environmental stringency on productivity, the labour services index (LAB) is added to get differences in the scale of operations across countries and over time. Higher labor input levels may indicate a greater industry ability to put means into R&D or absorb new technologies. This analysis also includes intangible assets (CAPIntang) as a control, capturing investments in R&D, software, and intellectual property. These assets are more closely linked to innovation capacity and are particularly relevant in sectors undergoing technological transformation, like the automotive industry. As shown by Ajayi et al. (2023), intangible capital plays a key role in driving capital input growth at the economy-wide level, suggesting it is a critical factor when assessing a firms' ability to respond to environmental regulation. Besides labor and typical capital regulations, the regressions also include tangible ICT capital contributions as another control (TangICT). This reflects the increasing agreement among researchers that digital and ICT-related investments are important for companies to deal with stricter environmental rules. For example, De Santis et al. (2020) found that strict environmental policies tend to increase productivity more in countries with greater ICT use, implying that ICT capital helps companies adjust and raise efficiency. Finally, gross value added (ln_GVA) is included to account for output levels and ensure productivity and innovation responses are not simply driven by changes in economic scale. It was transformed into a logarithm to bring the values into a more comparable scale. Together, these controls make sure estimated results are not caused by wider structural shifts in production capacity or labor input, but show the link between policy and firm behavior.

$$TFP_{it} = \beta_0 + \beta_1\, ln(innovation)_{it} + \beta_n Controls_{it} + \varepsilon_{it} \tag{2}$$

Where:

- TFP_{it} represents the total factor productivity,
- The other variables are the same as in regression (1).

This regression will analyse the second part of the strong Porter Hypothesis, i.e. the impact of innovation on productivity.

$$ln(innovation) = \beta_0 + \beta_1\, EPSI\_lag_{it}\#\#Country_{it} + \beta_n Controls_{it} + \varepsilon_{it} \tag{3}$$

$$TFP_{it} = \beta_0 + \beta_1\, ln(innovation)_{it}\ \#\#Country_{it} + \beta_n Controls_{it} + \varepsilon_{it} \tag{4}$$

Regressions 3 & 4 test, similarly as for 1 & 2, the impact of environmental policy stringency on innovation, followed by the impact of the latter on competitiveness. However, this part aims to test the difference between each country. For this regression, the same variables will be used than for the previous ones. To reduce the risk of endogeneity and better reflect how firms react to regulation, lagged values of the EPSI (epsi_lag) were included. As Rubashkina (2015) explains, firms may not respond immediately to new regulations, since R&D takes time to organize and carry out. Using lagged policy variables helps capture this delayed reaction. Similarly, Benatti et al. (2024) also use lagged EPSI to avoid reverse causality, where innovation might influence policy instead of the other way around. Including lags allows for a better estimate of how environmental regulation affects innovation over time. Furthermore, interacting (represented by ##) epsi_lag with country dummies enables separate coefficients for the effect of environmental policy stringency on R&D in each country, rather than assuming a homogeneous effect across the panel. The same goes for the second part of the PH, where R&D is interacted with the countries in order to estimate its impact on TFP, using the same controls.

In conclusion, this research uses fixed-effects panel regression along with chosen control variables to find the link between strict environmental policy, innovation, and how well the automotive industry of each country compete. By looking at changes across countries and time, the model tries to make sure the results are reliable and can be compared.

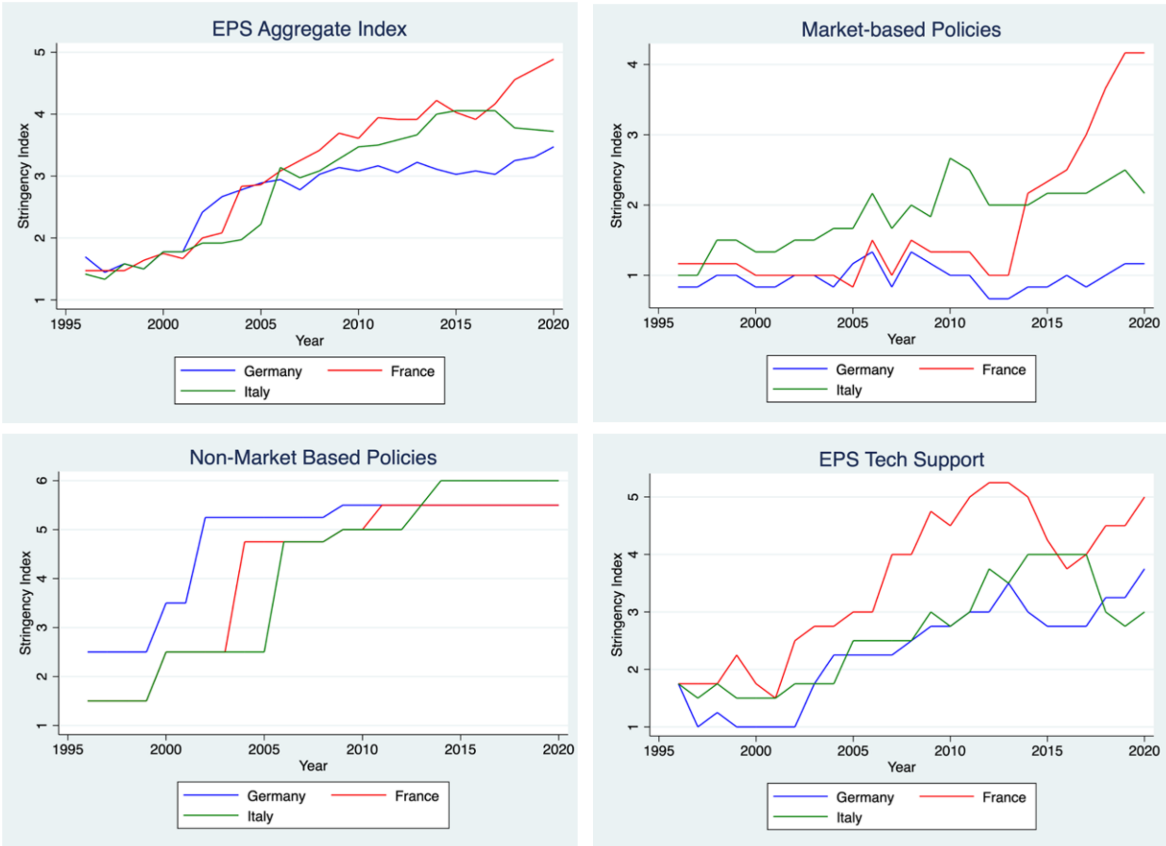
5. Data

The analysis uses two different sources of data to answer the RQ. The OECD Environmental Policy Stringency Index, as well as the EU Klems, which brings macro and aggregate indicators for the involved countries.

5.1 Environmental Policy Stringency Index

The Environmental Policy Stringency (EPS) Index was created in an atmosphere where the demand for climate research is booming. It encompasses data across 40 countries, 13 policy instruments, ranging from 1990 to 2020. By doing so, the OECD allowed for a quantification of climate policies, which further offers the possibility to identify the leaders and laggards in the climate race (Kruse et al., 2022). The index itself is built by scoring selected policies on a scale from zero to six based on their stringency, and then aggregating these scores. The strength of the indicator lies in its ability to simplify a complex array of policies into a single, country-specific measure that allows for cross-country comparison, like for this study (Albriizio et al., 2017). The index consists of three equally weighted sub-sections; market-based policies, non-market based policies and technology support. Each of these are subdivided into different policies, but for the relevance of this research, only the aggregate EPS index will be considered. However, the EPS index has certain limitations, primarily due to its narrow focus on policies targeting greenhouse gas emissions and local air pollution. It does not account for environmental regulations in other sectors, such as water, biodiversity, or waste management, largely because consistent cross-country data in these areas is lacking (Kruse et al., 2022).

Figure 2: Environmental Policy Stringency Index (EPSI) in Germany, France, and Italy (1995-2020), by policy type.



Note. Created using data from the OECD EPSI database

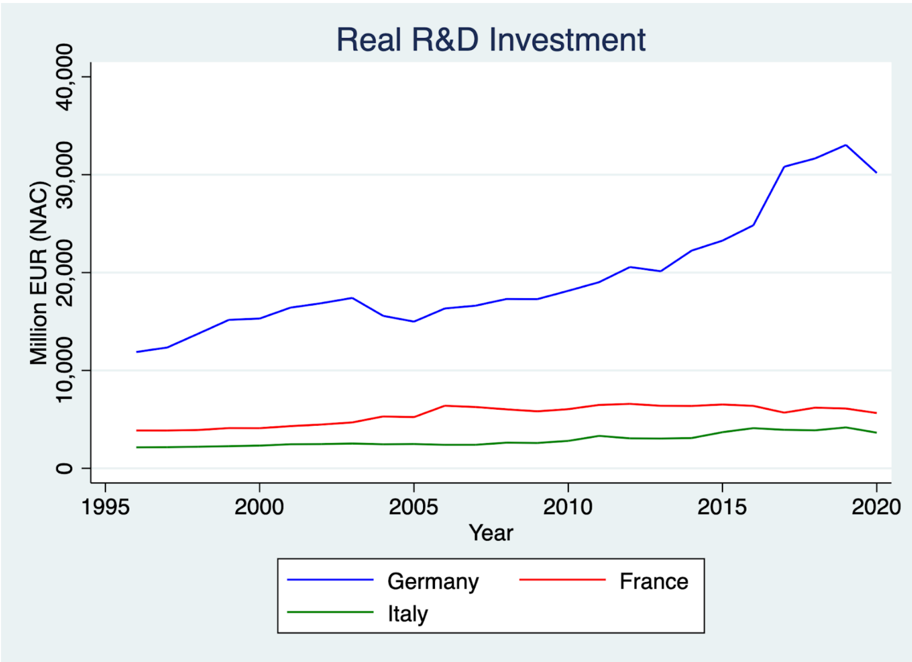
Figure 2 depicts the evolution of environmental stringency for the three countries, and for each sub indicator. Though trends are roughly similar, there is some heterogeneity across the levels of stringency per country, with France tending to have a higher level of stringency. The general trend, in line with the policy review, points towards an overall increase in policy stringency. Germany and Italy both seem to favour non-market based policies, while France has a high level on all three indicators. Germany's higher EPSI score for non-market-based policies aligns with its state-driven approach to environmental regulation. As seen in the policy overview, initiatives like the Energiewende, Clean Air Plan, and National Electric Mobility Platform reflect a strong reliance on regulatory instruments and strategic planning rather than market-based tools (Ragonnaud 2024, Krzywdzinski et al., 2022).

However, it is important to note that these indices reflect economy-wide environmental stringency and do not isolate policies targeting the automotive sector specifically. Therefore, while they provide valuable insight into national environmental policy trends, they may not fully capture sector-specific dynamics, particularly in industries like automotive where competitiveness and regulatory exposure can vary significantly from the national average.

5.2 EU Klems

In order to measure innovation (proxied by R&D), and competitiveness (proxied by total factor productivity), the database of EU Klems will be used. EU KLEMS stands for EU level analysis of capital (K), labour (L), energy (E), materials (M) and service (S) inputs. The database provides industry-level panel data for EU member states, allowing for consistent cross-country comparisons of input use and productivity over time. To proxy for innovation, real R&D investment measured as research and development expenditure in chain-linked volumes (2015 base year) from the EU KLEMS database will be used. This reflects inflation-adjusted R&D activity in NAC mn (million in national currency), allowing for consistent comparisons over time and across countries (Ambec & Lanoie, 2008; Rubashkina et al., 2015). To measure productivity, the annual total factor productivity (TFP) growth in percentage points (p.p.) will be used, which reflects year-over-year changes in output, and is commonly used to express competitiveness (Benatti et al., 2024; Rubashkina et al., 2015).

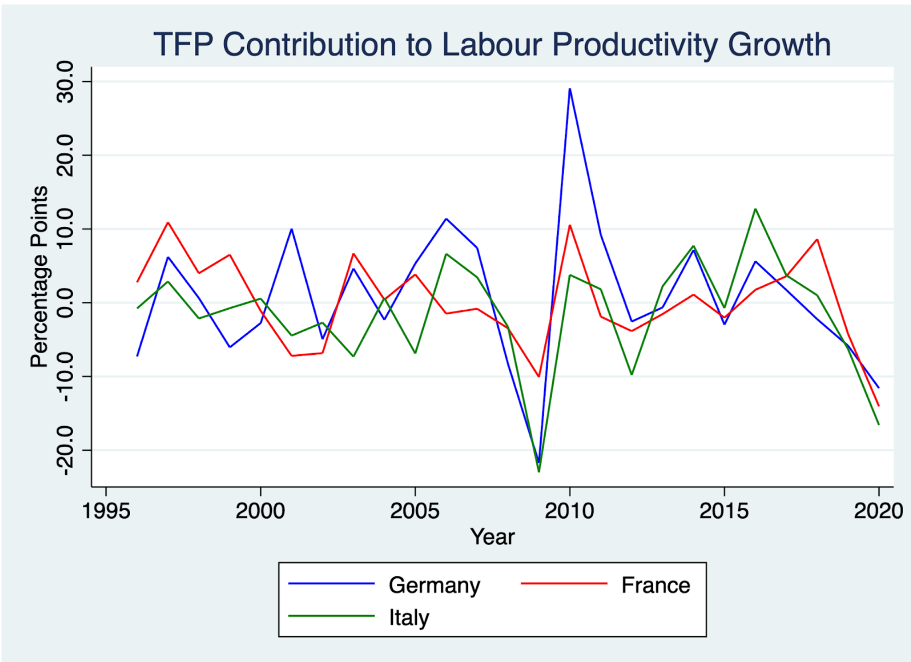
Figure 3: Real R&D investment in the automotive sector in Germany, France, and Italy (1995-2020).



Note. Created using data from the EU KLEMS database

The evolution of R&D investment depicted in Figure 3 for the automotive industry across Germany, France, and Italy highlights distinct national approaches to innovation. Germany shows a clear and sustained increase in automotive R&D investment from the mid-2000s onward, likely driven by a growing policy focus on electrification. The spike in 2015 is likely to have occurred following events such as the Dieselgate scandal and the implementation of initiatives like the National Electric Mobility Platform (Unnerstall, 2017). In contrast, R&D investment in France and Italy remains comparatively flat, reflecting more constrained innovation dynamics within their automotive sectors. In France, this aligns with a history of fragmented industrial strategy and delayed policy support (Aussilloux et al., 2020). Italy's consistently lower R&D levels underscore structural limitations, including weaker state involvement and fiscal policies that discourage modernization (Calabrese, 2020). These trends suggest that, within the automotive sector, Germany has been more successful in aligning environmental goals with R&D in the industrial sector, while France and Italy have been slower in investing in R&D.

Figure 4: TFP contribution to labour productivity growth in Germany, France, and Italy (1995-2020).



Note. Created using data from the EU KLEMS database

The TFP contribution to labour productivity growth shown in Figure 4 further illustrates different performances within the automotive sector. Germany exhibits considerable year-to-year volatility, including a sharp spike around 2010, likely reflecting the post-financial crisis rebound and restructuring efforts. France's trajectory is more stable but remains consistently below Germany's highs, indicating modest but more predictable productivity contributions from total factor inputs. Italy shows the weakest TFP performance overall, with frequent negative contributions and limited upward peaks, reinforcing the view that the sector struggles to convert input use into productivity gains. These differences suggest that Germany's automotive industry may be better positioned to use innovation and adapt to regulatory shifts, while France and Italy face deeper structural challenges in enhancing productivity through technological change.

Table A: Descriptive Statistics					
Geo_code	Variable	Mean	SD	Min	Max
DE	*TFP*	.7686832	9.647988	-21.73073	29.06926
	ln_RD	9.844327	.286416	9.383192	10.40545
	epsi	2.688889	.6461941	1.444444	3.472222
FR	*TFP*	.0867819	6.140309	-14.06047	10.921
	ln_RD	8.590055	.1932603	8.258594	8.793359
	epsi	3.143333	1.135516	1.472222	4.888889
IT	*TFP*	-1.498937	7.51181	-23.00122	12.76525
	ln_RD	7.945799	.2172111	7.669782	8.338499
	epsi	2.861111	.9884557	1.333333	4.055555

Table A presents descriptive statistics for the main variables of interest across the three countries. Germany shows the highest average R&D investment (log-transformed), followed by France and Italy. In terms of total factor productivity, all countries display wide variation, with Germany showing the highest mean, while Italy has a negative average TFP over the period. The EPSI scores also vary, with France having the highest average stringency, suggesting stronger environmental regulation relative to Germany and Italy, as can be seen in figure 2. These patterns provide aggregate insight into country-specific differences in innovation, productivity, as well as regulatory context.

6. Results

In the following section, the results of each regression will be given.

Table 1: Multiple Regressions on ln_RD: Regressions 1.1 to 1.5					
Variable	*1.1*	*1.2*	*1.3*	*1.4*	*1.5*
epsi	- 0.117	0.004	0.028	0.061	0.052
	(0.9584)	*(0.047)*	*(0.068)*	*(0.057)*	*(0.07)*
Lab		0.01	0.003	-0.003	-0.004
		(0.005)	*(0.001)*	*(0.004)*	*(0.002)*
CapIntang			**0.014***	**0.015*****	**0.16****
			(0.002)	*(0)*	*(0.001)*
ln_GVA				0.268	0.302
				(0.173)	*(0.113)*
TangICT					0.34
					(0.603)
Year FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Clustered SEs	Yes	Yes	Yes	Yes	Yes
N	75	75	75	75	75
Within R^2	0.849	0.877	0.943	0.952	0.953

Notes. F-statistic not reported due to clustering with only 3 groups. Standard errors in parentheses and italics. Standard errors in parentheses and italics. Year fixed effects were retained in all models, even though they did not show a statistically significant contribution. p< 0.05 (*), p< 0.01 (**), p< 0.001 (***)

The table presents the results of five fixed-effects regressions testing the relationship between environmental policy stringency (EPSI) and R&D investment, measured as the logarithm of R&D (ln_RD), and represents the first part of the analysis of the strong PH. All models include year fixed effects, country fixed effects, and standard errors clustered at the country level.

In the first model, which only includes EPSI as an explanatory variable, the coefficient for EPSI is -0.117 with a standard error of 0.958, indicating a negative but highly imprecise estimate. As controls are progressively added in subsequent models, the coefficient for EPSI changes both in magnitude and direction. In model (2), where labour services (Lab) is added, the EPSI coefficient becomes 0.004 with a standard error of 0.047. In model (3), with the addition of intangible capital (CAPIntang) the coefficient increases to 0.028 (SE = 0.068). It rises further to 0.061 (SE = 0.057) in model (4) with the inclusion of real gross value added (ln_GVA), and finally reaches 0.052 (SE = 0.070) in model (5), which includes all controls.

The coefficient for labour quality is small across all models in which it is included, ranging from 0.010 to -0.004, with standard errors between 0.001 and 0.005. These estimates are not statistically significant. In contrast, intangible capital is consistently positively associated with R&D investment. From model (3) onward, its coefficient increases from 0.014 to 0.16, and all estimates are statistically significant at the 5% or 1% level. The coefficient for ln_GVA is included in models (4) and (5), with values of 0.268 and 0.302, respectively, and standard errors of 0.173 and 0.113. Finally, tangible ICT capital (TangICT) is included only in the final model, where its coefficient is 0.340 with a standard error of 0.603.

Table 2: Multiple Regressions on TFP: Regressions 2.1 to 2.5

Variable	*2.1*	*2.2*	*2.3*	*2.4*	*2.5*
ln_RD	-6.08	-10.419	-13.7	-17.721	-18.416
	(2.862)	*(6.6)*	*(7.52)*	*(5.009)*	*(5.634)*
Lab		0.152	0.133	-0.055	-0.084
		(0.133)	*(0.121)*	*(0.158)*	*(0.215)*
CapIntang			0.084	0.175	0.197

			(0.031)	*(0.049)*	*(0.085)*
ln_GVA				7.548	8.869
				(2.656)	*(4.228)*
TangICT					9.87
					(10.202)
Year FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Clustered SEs	Yes	Yes	Yes	Yes	Yes
N	75	75	75	75	75
Within R^2	0.703	0.71	0.711	0.717	0.718
Notes. F-statistic not reported due to clustering with only 3 groups. Standard errors in parentheses and italics. Year fixed effects were retained in all models, even though they did not show a statistically significant contribution.					

This table shows the second part of the strong PH analysis; i.e. the impact of innovation (R&D) on competitiveness (TFP). As for the previous table, five models including year fixed effects, country fixed effects, and clustered standard errors at the country level, present the results with controls progressively added. Across all models, the coefficient for R&D remains negative and increases in magnitude as controls are added, but remains statistically not significant. Tangible capital and gross value added also show consistently positive coefficients in the models. However, the results remain insignificant, with high SEs for ln_RD.

Table 3: Multiple Regressions on ln_RD: Regressions 3.1 to 3.5					
Variable	*3.1*	*3.2*	*3.3*	*3.4*	*3.5*
epsi_lag (GE)	-0.155	-0.111	-0.061	-0.122	-0.152
	(0.248)	*(0.154)*	*(0.12)*	*(0.083)*	*(0.1)*

epsi_lag (FR)	0.018	0.0948	0.082	0.134	0.17
	(0.111)	*(0.128)*	*(0.066)*	*(0.058)*	*(0.09)*
epsi_lag (IT)	0.033	0.082	0.016	0.109	0.139
	(0.107)	*(0.106)*	*(0.063)*	*(0.058)*	*(0.11)*
Lab		0.012	0.003	-0.003	-0.001
		(0.009)	*(0.004)*	*(0.004)*	*(0.09)*
CapIntang			**0.016***	**0.015***	0.014
			(0.002)	*(0.002)*	*(0.003)*
ln_GVA				0.357	0.33
				(0.233)	*(0.178)*
TangICT					-0.588
					(0.766)
Year FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Clustered SEs	Yes	Yes	Yes	Yes	Yes
N	75	75	75	75	75
Within R^2	0.837	0.873	0.955	0.959	0.961

Notes. F-statistic not reported due to clustering with only 3 groups. Standard errors in parentheses and italics. Year fixed effects were retained in all models, even though they did not show a statistically significant contribution. p< 0.05 (*), p< 0.01 (**), p< 0.001 (***)

This table presents the country-specific results for the effect of lagged environmental policy stringency on R&D investment, and aims to analyse the specific effects of policy stringency per country. Five fixed-effects models are reported, each including year fixed effects, country fixed effects, and clustered standard errors at the country level. Controls are progressively added across the models.

For Germany, the coefficient of epsi_lag remains negative across all specifications, while for France and Italy, the coefficients are positive throughout. However, none of the epsi_lag estimates for any country are statistically significant across the models. Labour quality shows very small and statistically insignificant coefficients in all cases. Intangible capital is almost consistently positive and is statistically significant at the 10% level. The coefficients for gross value added are only included in the last two models and remain positive. Tangible ICT is included only in the final model, where it shows a negative coefficient.

Table 4: Multiple Regressions on TFP: Regressions 4.1 to 4.5					
Variable	*4.1*	*4.2*	*4.3*	*4.4*	*4.5*
ln_RD (GE)	-5.075	-8.255	-2.567	-9.466	-8.133
	(3.155)	*(4.399)*	*(8.605)*	*(7.843)*	*(6.375)*
ln_RD (FR)	-10.614	-7.414	-8.717	-5.853	-11.047
	(2.968)	*(3.206)*	*(3.484)*	*(3.422)*	*(3.468)*
ln_RD (IT)	**3.335***	**5.131***	6.856	**17.939***	20.398
	(0.611)	*(0.767)*	*(2.495)*	*(2.943)*	*(4.814)*
Lab		0.093	0.118	-0.228	-0.441
		(0.046)	*(0.651)*	*(0.06)*	*(0.198)*
CapIntang			-0.14	-0.081	-0.051
			(0.137)	*(0.134)*	*(0.088)*
ln_GVA				**18.547***	27.063

				(3.383)	*(7.714)*
TangICT					**48.01***
					(9.628)
Year FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Clustered SEs	Yes	Yes	Yes	Yes	Yes
N	75	75	75	75	75
Within R^2	0.723	0.724	0.726	0.751	0.763
Notes. F-statistic not reported due to clustering with only 3 groups. Standard errors in parentheses and italics. Year fixed effects are included for consistency, although their impact was not statistically significant in the full model. $p< 0.05$ (*), $p< 0.01$ (**), $p< 0.001$ (***)					

This table reports the country-specific results for the effect of R&D investment on TFP, using an interaction model for Germany, France, and Italy. Five fixed-effects models are presented, progressively adding additional controls. For Germany and France, the coefficients for R&D remain negative across all specifications, whereas for Italy the coefficients are consistently positive and in some cases statistically significant. This suggests that, in certain cases, R&D in Italy is more strongly associated with higher TFP compared to the other two countries. Labour and intangible capital show small and insignificant effects. Gross value added is positive and significant in one of the models, while tangible ICT capital becomes positive and significant only in the final specification.

7. Discussion of Results

The analysis of the strong Porter Hypothesis, illustrated by hypothesis 1 & 2, shows largely statistically insignificant relationships, which offers important insights into the broader Porter Hypothesis debate. In the first part of the PH, stricter environmental policy stringency did not significantly stimulate R&D, and in some models the estimated effect was even negative, though not robust. Likewise, higher innovation showed no clear increase in terms of competitiveness, proxied by total factor productivity (TFP). If anything, the coefficients on R&D in the TFP models were negative, although statistically insignificant.

These patterns suggest that, within this sample, there is little evidence that increased environmental policies automatically drive innovation, as was suggested by Porter & Van der Linde (1995). However, these findings stand in line with a growing body of literature that questioned the validity of the PH. For example, Ambec et al. (2013) note that while the weak version of the Porter Hypothesis has received considerable empirical support, evidence on the strong version remains mixed. The results align with the literature: no robust findings on innovation offsetting or competitiveness gains that would confirm the strong Porter Hypothesis in the automotive sector of these countries.

Notably, the large presence of statistically insignificant coefficients in our study mirrors the broader academic findings that such results are common. Cohen and Tubb (2018), in a meta-analysis of 103 studies, report "*considerable heterogeneity in both the sign and significance*" (p. 371) of estimated effects, and observe that in most cases (51%) the relationship between environmental regulation and productivity is statistically insignificant. This lack of evidence in the context of the strong PH was also found in the study by Rubashkina et al. (2015) on European manufacturing sectors. They found that environmental regulation did not have an impact on R&D, and that a higher stringency did not harm productivity, and the overall effect was neutral. In other words, across many contexts the most typical finding has no clear effect, also what can be observed in these results. This lack of significance does not necessarily mean that environmental policy has no impact on innovation or performance, rather, it suggests that any effects are highly context-dependent and often offset by costs or other factors. Cohen and Tubb (2018) further highlight that the relationship between environmental regulation and competitiveness depends on the level of analysis. They found that negative or insignificant effects are more commonly reported in industry level studies, while more aggregated country-level studies tend to offer positive correlations. This distinction is important for interpreting the present findings. Since this thesis operates at the industry level within countries it aligns more closely with the type of studies where null or mixed results are typical.

The findings of innovation having negative (though not statistically significant) effects on TFP is consistent with the study by Palmer et al. (1995), who argued that compliance with more stringent policies might increase R&D investment, but that the benefits of the latter were not guaranteed to be enough to offset the costs of compliance. In other terms, not all regulation leads to innovation, only well-designed regulations do, and even then that innovation produces gains in productivity is uncertain. However, in this study, the EPSI is a broad economy-wide measure that combines various regulations (market-, non-market-based and technological support), primarily targeting emissions and air pollutants. The generally null findings could indicate that the mix of policies in Germany, France, and Italy during the study period may not have provided the right kind of incentives. Nonetheless, the specific impact of these different types of regulations were not the object of this particular study, and could be the object of further research. In sum, when viewed against the broader academic debate, the evidence reinforces the idea that the strong Porter Hypothesis is not a universal law, and that stringent environmental policies do not automatically improve innovation or competitiveness.

While the overall results tend to not deliver statistically significant results, the country-specific analysis revealed differences between Germany, France, and Italy. Each country's automotive sector responded to environmental stringency and subsequent innovation and competitiveness in different ways, likely reflecting underlying structural and policy differences.

Germany's automotive sector did not exhibit a statistically signficant innovation-productivity relationship during the period. The R&D to TFP coefficient for Germany is negative (ranging from -5.075 to -9.466 across models). This is worth noting because of the fact that Germany is generally seen as an innovation leader with high R&D spending. One possible explanation is that much of the R&D in German automotive firms during the 2000s and 2010s went into EV areas, sparked by the 2015 Dieselgate scandal, whose benefits might not immediately be translated into higher productivity and possibly with benefits that fall outside the time frame of this analysis (Unnerstall, 2017; Krzywdzinski et al., 2022).

This pattern is also reflected in the policy stringency regressions. The EPSI-lag coefficient for Germany is consistently negative and statistically insignificant, suggesting that stricter environmental policies did not significantly stimulate additional R&D investment in the

German automotive sector. This could indicate that German firms initially met tightening EU standards and Energiewende policies by reallocating resources to compliance and legal costs rather than increasing innovation. Overall, Germany's high level of R&D and stringent policy framework did not lead to an observable increase in productivity over the two-decade period analyzed, highlighting one of the key limitations of the strong PH. Within this context, there is no clear evidence that stricter regulation stimulated innovation, nor that any innovation translated into measurable competitiveness gains.

France's results lie somewhere in between. Like Germany, France showed no meaningful gains in automotive TFP attributable to R&D, with negative and insignificant coefficients for ln_RD (between -7.414 and -11.047). In the first part of the analysis, the lagged EPSI coefficient was positive but very small and insignificant (0.018 to 0.134), suggesting that environmental policy pressures were not a primary driver of innovation investment in its automotive industry. Structurally, this aligns with the long-term decline and deindustrialization of the French automotive industry, as well as the fragmented policy support (Aussilloux et al., 2020; Pardi, 2019). As a result, French automakers did not significantly increase R&D in response to tightening EU emissions standards, potentially contributing to the insignificant results presented. Consequently, like Germany, France showed no evidence supporting the strong Porter Hypothesis, as policy stringency did not significantly stimulate innovation nor translate into improved competitiveness.

By contrast, it is important to clarify what the Italy coefficient actually represents. In the second interaction model, the Italy term (+3.335) is statistically significant, but this significance only indicates that the relationship between Italy's R&D and TFP significantly different from Germany's. It does not mean that Italy's relationship is significantly positive on its own. When combining the Italy interaction term with Germany's coefficient (-5.075), the total effect for Italy remains slightly negative (-1.74) and statistically insignificant. In other words, Italy's automotive sector experienced a less negative link between R&D and productivity compared to Germany, but we still cannot conclude that R&D investments in Italy led to measurable productivity gains. This nuance is important to note, as it shows that while Italy may have responded better than Germany and France, none of the three countries showed a robust innovation-competitiveness relationship. Nevertheless, Italy's overall innovation spending remains the lowest of the three countries, and without a strategic industrial policy for electrification, the relative advantage of a lesser negative R&D-TFP relation is unlikely to secure long-term competitiveness. This result is somewhat surprising given Italy’s aforementioned industrial challenges, as Italy’s automotive industry has historically lagged in technology adoption and efficiency gains (Calabrese, 2020). Furthermore, looking at the EPSI-to-R&D regressions, the Italian coefficients are small and statistically insignificant, indicating that increasing environmental policy stringency did not lead to higher R&D spending in Italy’s automotive sector.

These country-specific results underline the limits of the strong Porter Hypothesis. While the strong PH predicts that stricter environmental regulation stimulates innovation which, in turn, improves competitiveness, our results show no robust evidence of such a positive pattern in any of the three countries. Germany and France, despite higher R&D spending and stricter policies, did not experience measurable productivity benefits. Italy performed ‘less badly’ in relative terms, but still failed to show a statistically significant increase in productivity. The findings support more cautious interpretations of the PH, aligning with studies like Cohen & Tubb (2018) and De Santis et al. (2020), which found mixed or insignificant effects.

Ultimately, these results reinforce the idea that context matters: the effect of environmental policy on both innovation and competition relies on the industry structure and the way policy is designed. Germany’s advanced innovation system may require for benefits to appear, while France’s fragmented approach limited its policy response; and Italy's small but focused modernization caused no obvious gains in output. These nuanced outcomes show why one-size-fits-all expectations of the Porter Hypothesis do not hold in practice, particularly in complex industries like automotive that deal with disruptive technological shifts.

8. Conclusion

This thesis attempted to examine and answer the research question on whether stricter environmental regulation stimulates innovation and improves competitiveness in the European automotive sector, focusing on Germany, France, and Italy throughout the years 1996 to 2020. The results do not provide statistically significant support for the strong version of the Porter Hypothesis. Environmental policy stringency did not show a clear or consistent link to increased R&D investment, and, in turn, higher R&D levels were not associated with statistically significant gains in total factor productivity. While there were some differences between countries, with Italy's results appearing less negative than those of Germany and France, none of the three showed a robust relationship between regulation, innovation, and competitiveness. In other words, the expected 'win-win' scenario, where stricter policies would drive cleaner technologies and an increased competitive advantage, was not observed in this case. The results of this thesis contribute to the academic discussion on the Porter Hypothesis by adding evidence from a sectoral and country-specific European context. They align with some of the existing literature, which has often found support for the weak version of the hypothesis but mixed or inconclusive evidence for the strong version. Even in an industry with high R&D intensity and significant regulatory pressure, the anticipated link between regulation-induced innovation and productivity improvements did not emerge. This suggests that the strong Porter Hypothesis is far from universal and may depend on specific conditions such as policy design, time horizon, and the type of innovation being encouraged. By focusing on the automotive sector in three major EU economies, this study highlights that even where regulation and innovation activity are prominent, like in Germany, productivity gains are not guaranteed. Future research could expand the scope by including more countries, using firm-level data, or exploring alternative ways of measuring innovation and competitiveness.

For managers and decision-makers in the automotive industry, these findings carry important lessons. The absence of an immediate productivity payoff from green innovation suggests that simply complying with environmental policies will not automatically generate a competitive edge, as was initially set out by Porter & Van der Linde (1995). Firms should therefore approach environmental regulation strategically, integrating it into broader innovation and investment plans rather than relying on regulatory pressure alone to create beneficial change. This means looking beyond short-term costs and focusing on how environmental policies can be turned into opportunities for long-term capability building in a way that not only meet regulatory requirements, but also improve efficiency over time.

The findings also have implications for corporate social responsibility and overall sustainability strategies. Even though this study did not find a clear short-term link between green innovation and productivity, firms should not interpret this as a reason to deprioritize environmental efforts. Regulatory compliance remains essential, not only to meet legal requirements but also to maintain credibility with stakeholders and to prepare for changing market conditions. Sustainable innovation should therefore be viewed as a long-term investment in resilience and reputation, rather than a quick route to immediate productivity gains. By continuing to invest in cleaner technologies and integrating sustainability into their core strategies, firms can position themselves to benefit from the growing demand for low-emission solutions and to remain competitive as markets evolve. In this sense, CSR-oriented innovation can create value beyond short-run productivity, by strengthening a company's position on the green market, as well as its capacity to comply with regulations.

However, it is also important to reflect on the global context. China's rapid rise as a global leader in electric vehicle production and innovation appears to be less the result of environmental regulation, and more the outcome of economies of scale and a stronger technological edge (Draghi, 2024). This challenges the assumption at the core of the Strong Porter Hypothesis, that stricter environmental policies alone can drive competitiveness. In contrast to the European approach, which relies a lot on regulation, China's success shows the importance of larger industrial strategies.

In conclusion, this thesis shows that stricter environmental regulation, while necessary for addressing climate challenges, does not automatically deliver productivity or competitiveness gains in the European automotive industry. Both policymakers and managers should be realistic about what regulation can achieve on its own and recognize the need for complementary strategies to gain the potential benefits of green innovation. The findings emphasize that aligning sustainability and competitiveness is possible but requires more than regulatory pressure, it demands a willingness to innovate beyond compliance.

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