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Beyond Porter hypothesis: Empirical evidence of heterogeneous and contextual economic returns of eco-innovations on a sample of European SMEs

Samira Rousselière^{a,e}, Thomas Coisson^{b,e}, Mahmoud Hassan^c, Anne Musson^d,
Damien Rousselière^{b,e,*}

^a LEMNA, Université de Nantes, Oniris, Nantes, France

^b Institut Agro, INRAE, SMART, Angers, France

^c Bordeaux Sciences Economiques, Université de Bordeaux, CNRS, Bordeaux, France

^d ESSCA School of Management, SMART, Angers, France

^e Institut de Recherche en Sciences et Techniques de La Ville, CNRS, Nantes, France

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ABSTRACT

The various versions of the Porter hypothesis suggest that well-designed environmental public policies may have positive effects on eco-innovation adoption and on the profitability of enterprises on the long run. However, these effects may be heterogeneous depending on the eco-innovation at stake and influenced by the other enterprises in competition. Using a repeated cross-country European survey on SME, we estimate mixed Ordered Probit with correlated random effects and sample selection. We are able to disentangle direct and indirect determinants of costs while accounting for the internal, contextual and public policies levers of eco-innovation adoption. While testing the three versions of Porter's hypothesis, we extend previous work by taking into account the heterogeneous impact of different eco-innovations on profitability, on the one hand, and the impact of eco-innovation adoption by one firm on another, on the other hand. Our results have valuable policy implications for policymakers and SMEs.

1. Introduction

The transition of companies towards a more sustainable and environmentally-friendly economy is a key political issue, with Circular Economy (CE) approaches serving as a major lever. Beyond recycling initiatives, these approaches encompass sustainable resources and waste management strategies, such as enhancing resource efficiency, creating markets for secondary products, and reducing exposure to geopolitical supply risks (Livingstone et al., 2022). Within this broad definition, eco-innovations (EI) implemented by private companies contribute to various components of the Circular Economy, including sustainable sourcing, eco-design or the use of renewable energies sources (Stewart and Niero, 2018). Consequently, economic literature has increasingly focused on how to incentivize private companies to adopt such strategies. Notably, small and medium-sized enterprises (SMEs) are of particular interest, as they represent 99% of all businesses in the

European Union, account for two-thirds of private sector employment and more than half of the added value created.¹

Academic discussions on the influence of environmental policies on the adoption of environmental innovations frequently center on the well-known Porter Hypothesis. This hypothesis posits that “properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs of complying with them” (Porter and van der Linde, 1995). According to Ambec et al. (2013) numerous studies provide empirical evidence supporting the “weak” version of the Porter Hypothesis, which asserts a positive link between environmental regulation and innovation. However, the actual effects on production costs and business performance (the “strong” version) are mixed and vary depending on the case studies (Cohen and Tubb, 2018). Antonioli et al. (2022) confirm that the economic returns of circular economy practices, particularly for SMEs, show similarly mixed evidence. Several factors contribute to this lack of clearly identified effect, each of which

* Corresponding author. Institut Agro, INRAE, SMART, Angers, France.

E-mail address: damien.rousseliere@institut-agro.fr (D. Rousselière).

¹ <https://www.europarl.europa.eu/factsheets/en/sheet/63/petites-et-moyennes-entreprises>.

represents a research gap that we aim to address.

Lanoie et al. (2011) identify two distinct and opposing effects: a direct negative effect of stringent environmental policies on business performance, and an indirect positive effect via increased R&D investment, which subsequently enhances business performance. While their study finds the direct effect to be dominant, the coexistence of these effects may explain the variability in results across different countries or sectors, thus necessitating further empirical analysis. Ghisetti and Rennings (2014) argue that distinguishing between different types of environmental innovations is crucial, as they may lead to heterogeneous profitability effects. For example, EI aimed at improving resource and energy efficiency tend to positively influence financial performance, whereas those focused on reducing externalities, such as harmful materials and pollution (air, water, noise, and soil), are associated with weaker financial outcomes. Additionally, the variability in empirical evidence can be attributed to the heterogeneity of environmental regulations tested, leading to a third variant of the Porter Hypothesis—the "narrow" version—which suggests that the impact of regulation depends on the type of policy implemented. More flexible regulation tends to provide stronger incentives to innovate (Ambec et al., 2013). While the role of environmental regulation in innovation adoption and business performance presents a complex conceptual framework, it is essential to note that the decision to adopt EI also depends on other factors, including competitive effects.

Our research seeks to fill the existing gap by providing a more nuanced understanding of the relationship between environmental regulation and production costs, while considering the various levers for engaging in diverse EI strategies. We focus on the case of EI adoption by European SMEs. Utilizing a repeated cross-country European survey, we estimate mixed Ordered Probit models with correlated random effects and sample selection. This approach allows us to disentangle the direct and indirect determinants of costs while accounting for internal, contextual and public policies levers that influence EI adoption.

Our contribution is at the methodological and empirical levels. At the methodological level, we combine macro and micro data to examine the impact of environmental policy instruments on EI and their economic returns for SMEs. In comparison with previous studies, using the same data (e.g. Darmandieu et al. (2022) or Neumann (2021)), a distinctive and innovative feature of our econometric model is its ability to simultaneously test the three versions of the Porter Hypothesis while extending it to account for the heterogeneity and contextual effects of EI on profitability.

At the empirical level, our findings are threefold. While providing a general support for the strong version of Porter Hypothesis, we demonstrate that the impact of EI on production costs varies depending on the type of EI implemented, but is also shaped by the implementation of EI by competitors. Finally, we show that while non-market-based policies may reduce the overall probability of EI adoption, they can nonetheless lower production costs for SMEs that choose to implement EI.

The paper is structured as follows: drawing on existing literature, we formulate three hypotheses to be tested (section II) and present our data and methodological approach (section III). We then present our results (section IV) and conclude with a discussion on policy implications (V).

2. Literature review: motivations of adoption and impact of eco-innovation

2.1. Three standard versions of the Porter hypothesis

The literature illustrates how the determinants of SME adoption of EI relate to firm and entrepreneur characteristics (Del Brio and Junquera, 2003), as well as external factors such as market demand (Triguero et al., 2013). Kemp et al. (2023) categorize the barriers and drivers for EI based on whether they are internal to the company (e.g., environmental management, skills) or external (e.g., regulation, demand, financing

schemes). De Jesus and Mendonça (2018) emphasize that the levers and barriers to more sustainable behaviors among economic actors are not solely technical but also related to institutional factors, resistance to change, and economic or market limitations. Triguero et al. (2013) and Horbach (2008) propose classifying the determinants of EI activities into three pillars: supply-side factors, demand-side factors, and environmental policy influences.

Public policy objectives can be understood as efforts to encourage EI to reduce the negative environmental impacts of productive activities while enabling companies to generate wealth. Both objectives hinge on the validity of Porter's hypothesis, which posits that strict environmental regulations can stimulate innovation and enhance firm competitiveness in the long run. According to this hypothesis, environmental regulations, rather than being burdensome, can act as a catalyst for innovation, leading to improved operational efficiency, cost reductions, and new market opportunities. The strong version of the Porter Hypothesis asserts that environmental regulations not only stimulate innovation and enhance competitiveness but also lead to net economic benefits. The weak version suggests that environmental regulations create a context that incentivizes firms to innovate and adopt more sustainable practices, thereby reducing environmental impacts and potentially leading to long-term economic advantages (see Chen et al., 2022, for a comprehensive explanation). Empirical literature also shows that the absence of economic incentives and regulations negatively impacts EI in SMEs (see the systematic review by Passaro et al., 2023). Cecere et al. (2020) confirm that for European SMEs, access to public funds and fiscal incentives effectively promotes engagement in EI activities.

These considerations lead to our first two hypotheses.

- **H1 (Strong Porter Hypothesis):** *Environmental public policy stringency will benefit enterprise performance.*
- **H2 (Weak Porter Hypothesis):** *Environmental public policy stringency will encourage the adoption of eco-innovation*

In the literature, the narrow version of the Porter Hypothesis suggests that flexible regulation provides a stronger incentive for innovation than traditional regulation. Market-based and flexible instruments, such as emissions taxes, tradable allowances, or performance standards, are more conducive to innovation than technological standards, as they offer firms greater freedom in selecting technological solutions to minimize compliance costs (Ambec et al., 2013). Therefore, the narrow hypothesis comprises two sub-hypotheses.

- **H3a: (Narrow Porter Hypothesis a):** *There are negative or negligible effects of non-market-based environmental policy stringency on the adoption of eco-innovation.*
- **H3b: (Narrow Porter Hypothesis b):** *Market-based environmental policy stringency positively affects the adoption of eco-innovation.*

2.2. Heterogeneity and indirect effects

Eco-innovation encompasses a wide range of new or improved socio-technical solutions that preserve resources, mitigate environmental degradation, and/or enable value recovery from substances already in use within the economy (De Jesus and Mendonça, 2018). Consequently, one might expect heterogeneous economic returns. According to Palea et al. (2023), the economic benefits vary depending on the type of EI implemented: eco-design products contribute more to capital efficiency compared to recycling initiatives, waste reduction initiatives, or resource reduction. Eco-design, recycling and remanufacturing, may help firms improve their environmental performance while also boosting their financial performance; and improved environmental performance is believed to have a positive influence on firm performance (Magnano et al., 2024). In some cases, waste management can become profitable if innovative technologies enable the transformation of waste

into useful secondary raw materials for other applications (Gigli et al., 2019). Marin et al. (2015) analyze the eco-innovation profiles of SMEs in the European Union, demonstrating that these profiles—such as “Green champions” or “Non eco-innovators”—depend on the sector in which the companies operate. Their findings challenge the notion that all types of innovation within a company have uniform effects. Yan et al. (2022) provide a scientometric analysis of EI in SMEs, noting that few studies focus on the specific category of EI developed by SMEs and calling for further investigation. This study aims to examine the influence of EI characteristics on the profitability of European SMEs. The economic impact of EI may vary depending on the specific focus area, such as recycling, waste reduction, energy and water conservation, or the development of new sustainable products. This variation in impact leads to differing levels of interest among SMEs and, consequently, the need for differentiated public policy design. Using a theoretical production-economy model, Jin et al. (2023) demonstrate that certain EI may negatively impact profits. For instance, firms may fear potential market cannibalization by co-products. Hezarkhani et al. (2023) find similar effects for different circular economy strategies aimed at reducing food loss. Marketing “ugly vegetables” through traditional retailers may lead to demand cannibalization, reducing food loss on farms but potentially harming the farmer’s profit. However, marketing “ugly vegetables” through a dedicated retailer is likely to increase overall demand through competition.

These considerations lead to our fourth hypothesis.

- **H4.** *Eco-innovations exhibit heterogeneous profitability, with combined positive effect*

Another issue in the circular economy is the indirect impact of one firm’s adoption of EI on other firms. Examining competition among local authorities in Italy, Di Foggia and Beccarello (2018) and Ferraresi et al. (2023) find a positive impact of yardstick competition on the profitability of waste management initiatives. For example, Ferraresi et al. (2023) show that provinces imitate their neighbors in the separate collection of waste for recycling and recovery. This effect is more pronounced in pre-election years and is driven primarily by provinces where the president can run for re-election. However, in some cases, this process may negatively impact the profitability of all organizations involved. Investigating this hypothesis aims to provide insights into the controversial role of competition. As mentioned earlier, SMEs seek to enhance competitiveness through EI adoption, making competition a stimulus. However, competition can also limit financing possibilities, which are a key lever. In contrast, SMEs can effectively collaborate on EI, as demonstrated by Alcalde-Heras and Carrillo-Carrillo (2023), who highlight that horizontal collaboration with competitors positively impacts the overall EI portfolio of SMEs. This study analyzes the two opposing mechanisms: cooperation and competition.

These considerations lead to our fifth hypothesis.

- **H5.** *The benefit of eco-innovations to the economic performance for one given enterprise is influenced by the adoption of eco-innovations by other enterprises.*

The combination of these hypothesis leads to a generalized Porter Hypothesis that includes heterogeneous and indirect effects, as stated in Fig. 1.

For an EI i (with $i \in 1, \dots, n$), $H4.i$ and $H5.i$ may have (respectively) positive, null or negative impact on the economic performance of Enterprise A and Enterprise B . To be consistent with an expected combined positive effect of H1 and H2, H4 (with $H4 = \sum_{i=1}^n H4.i$) is suspected to have positive effect on the economic performance of Enterprise A . On the other hand, H5 (with $H5 = \sum_{i=1}^n H5.i$) remains indeterminate.

3. Methodology

3.1. Data and variables

We use two waves of Flash Eurobarometer (FL426 2015 and FL456 2017) which are part of the *SMEs, resource efficiency and green markets*² series. This survey was conducted by the TNS Political & Social network in 28 Member States of the European Union, as well as in Albania, North Macedonia, Montenegro, Serbia, Turkey, Iceland, Moldova, Norway, and, finally, the USA as a non-European benchmark economy. It covers businesses with one or more employees that are active in all sectors of the economy, except for agriculture and primarily non-market sectors (such as public administration, education, human health, and social activities, arts, and culture). The sectors covered account for approximately 87% of European Gross Domestic Product (GDP). The sample comprises 22,460 enterprises selected from an international business database, with quotas applied based on company size and sector.

As reported in descriptive statistics (Appendix 1), 41% of the enterprises in the sample have fewer than 10 employees, and only 6% have more than 250 employees. The distribution by sectors is as follows: 23% in manufacturing, 30% in retail, 31% in services, and 16% in other industries. The Flash Eurobarometer specifically focuses on SME and does not account for innovations implemented by larger companies. As highlighted by Nasiri et al. (2022), most research on sustainable innovation is already centered on large enterprises. However, the type and drivers of innovations may vary depending on the size of the enterprise, and it should be noted that SMEs account for a substantial share of pollution (Constantinos et al., 2010; Ukko et al., 2021). Therefore, even though our empirical findings are limited to SME, they may still be of great highly relevant for informing public policymakers.

Our analysis relies on two specific Eurobarometer questions that provide the variables of interest. The first question concerns eco-innovation (EI).

- **Q1:** What actions is your company undertaking to be more resource efficient?

Saving water; Saving energy; Using predominantly renewable energy (e.g. including own production through solar panels, etc.); Saving materials; Minimising waste; Selling your scrap material to another company; Recycling, by reusing material or waste within the company; Designing products that are easier to maintain, repair or reuse.

The nomenclature of the EI activities is consistent with the definition provided in the literature. As reported in Appendix 1, the main EI activity declared by the enterprise is energy saving (63%), followed by waste minimization (59%).

The least common activities are designing sustainable products (24%) and using predominantly renewable energy (15%). On average, enterprises engage in 3.4 activities (with a standard deviation of 2.22).

The second variable pertains to economic performance.

- **Q4:** What impact have the undertaken resource efficiency actions had on the production costs over the past two years? The production costs have ...

Significantly decreased; Slightly decreased; Slightly increased; Significantly increased; Not changed.

As shown by Parmeter and Kumbhakar (2014), literature on efficiency analysis has developed in three directions: maximization of production, maximization of profit, and minimization of costs. For Nowicki et al. (2023), there are five economic benefits of implementing circular economy such as cost reduction, avoiding financial penalties,

² See <https://europa.eu/eurobarometer/surveys/detail/2088> Data is available online at <https://doi.org/10.4232/1.12564>.

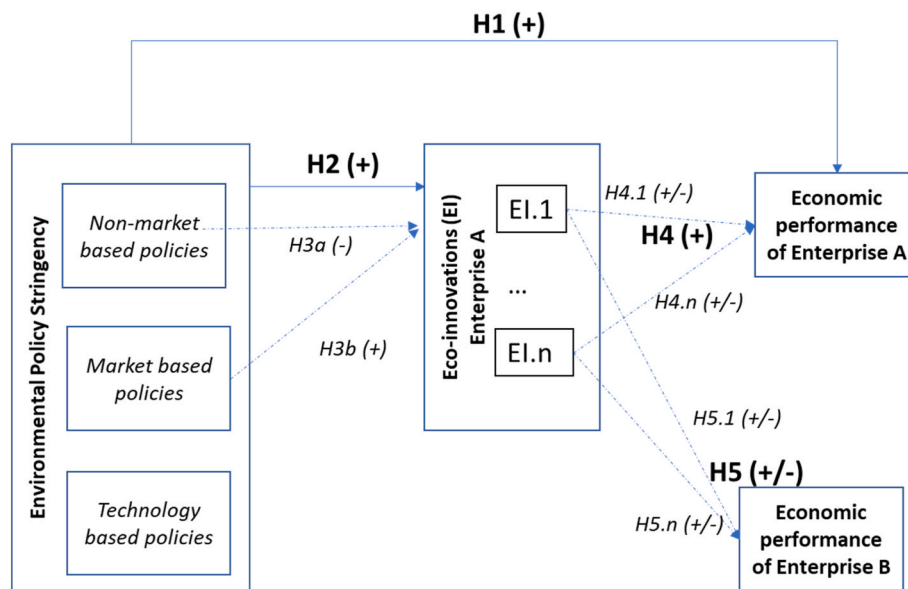


Fig. 1. Theoretical model.

increasing profit, gaining a competitive advantage and increasing market share. Therefore, it is reasonable in our case to use the only variable available, production costs, as a proxy for economic performance. In a recent systematic review, Hermundsdottir and Aspelund (2021) show that this variable has been used in 15 studies investigating 31 different relationships. In our sample, among the enterprises implementing EI, 6.3% observed a significant decrease in production costs, 50% reported a slight decrease, 15% noted a slight increase, and 4% experienced a significant increase. Approximately 24% did not observe any impact.

The environmental policy stringency index (EPS), initially developed by Botta and Koźluk (2014) on OECD countries and updated by Kruse et al. (2022), is used as an indicator of the stringency of environmental regulations. The revised version of EPS is based on 13 environmental policy instruments focusing on climate change and air pollution mitigation policies, including both market-based and non-market-based instruments, as well as technology support policies. Stringency is defined as the degree to which environmental policies impose an explicit or implicit price on polluting or environmentally harmful behavior. The EPS ranges from 0 to 6, where 0 represents the lowest stringency level (no policy), and 6 represents the highest. To assign the remaining scores, the difference between the 90th and the 10th percentile is divided into five equal bins that define the thresholds. Fig. 2 details the instruments used to construct the EPS index. The revised structure of EPS allows for a more granular analysis of the effects of environmental policies. For more information on this index, see Kruse et al. (2022).³

Following Del Río et al. (2016) and Rousselière et al. (2019), we selected variables that describe SMEs and may be considered as levers for EI in order to control for potential confounding effects, namely size (measured by the number of employees), turnover trend (increased/decreased/unchanged), age, target market (consumers, enterprises, public administration), and economic sector (manufacturing/retail/services/industry) (see Appendix 1).

3.2. Econometric model

Since we only know the impact on production costs for enterprises that actually implemented EI, our estimates may suffer from sample selection bias. As our outcome is measured using Likert Scale, we estimate therefore an ordered probit with sample selection that consists of

two equations (Greene and Hensher, 2010): the first one is related to the evolution of costs and, the second one is related to the probability of taking at least one action among the listed EI.

We have therefore:

$$\begin{cases} y_{ij}^* = \alpha_1 X_{1ij} + \epsilon_{1ij} \\ s_{ij}^* = \alpha_2 Z_{2ij} + \epsilon_{2ij} \end{cases} \quad (1)$$

With

$$\begin{cases} s_{ij} = 1 \text{ if } s_{ij}^* > 0, y_{ij} = \mu_{k-1} < y_{ij}^* \leq \mu_k \\ s_{ij} = 0 \text{ if } s_{ij}^* \leq 0, y_{ij} \text{ unobserved} \end{cases} \quad (2)$$

for an enterprise i in a country j , with X a vector of variables for the outcome equation, Z a vector of variable for the selection equation, ϵ_{ij} the error terms at the enterprise level which follow a normal distribution with a correlation θ_{12} .

Our model is extended as a correlated random effect (CRE) model (Mundlak, 1978; Wooldridge, 2010) to control for unobserved heterogeneity at the country level.

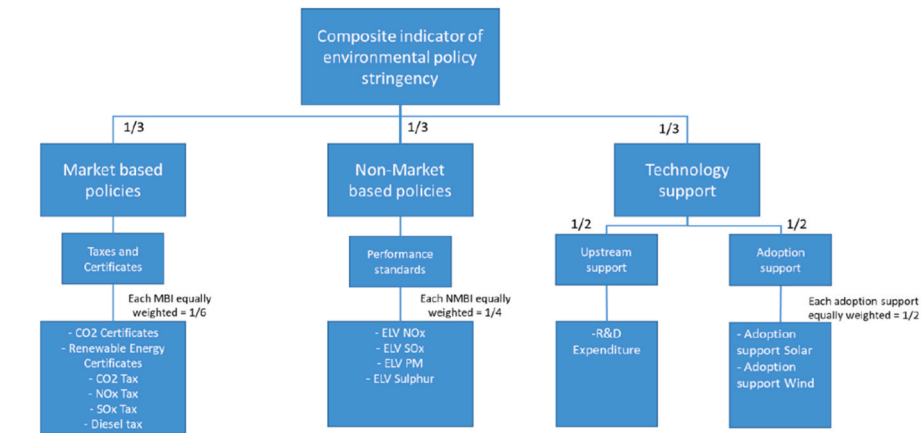
Including EI and EPS, the final model is therefore:

$$\begin{cases} y_{ij}^* = \alpha_1 X_{1ij} + \beta_1 \bar{X}_{1j} + \delta_1 EI_{1ij} + \zeta_1 \bar{EI}_j + \gamma_1 EPS_j + U_{1j} + \epsilon_{1ij} \\ s_{ij}^* = \alpha_2 Z_{2ij} + \beta_2 \bar{Z}_{2j} + \gamma_2 EPS_j + U_{2j} + \epsilon_{2ij} \end{cases} \quad (3)$$

with EI_{ij} a vector of EI variables at the enterprise level, EPS_j a vector of EPS dimensions at the country level, U the random effects at the country level which follow a normal distribution with a correlation φ_{12} . The correlated random effects models include the mean of country varying variables \bar{X}_j , \bar{EI}_j and \bar{Z}_j . A Mundlak test or VA (Variable added) test may be performed in order to assess the superiority of CRE model over random effect model (Wooldridge, 2010). Bayesian model selection based on AIC (Akaike Information Criterion) can also be used to select the best model (Burnham and Anderson, 2004). This system of equations is estimated using simulated maximum likelihood thanks to the CMP (Conditional Mixed Processes) algorithm (Roodman, 2011).

These averaged variables \bar{X}_j can be understood as the contextual effect as defined by Manski (1993): the propensity of an individual to behave in some way according to the characteristics of the group. In our case, the contextual effect is the average difference in the probability of innovation for two enterprises that differ by one unit on their country mean of a given variable. This is the potential differential effect on the

³ Data is available online at <https://doi.org/10.1787/2bc0bb80-en>.



Source: Kruse et al. (2022)

Fig. 2. The revised EPS index.
Source: Kruse et al. (2022).

response from belonging to groups or contexts with different means (Bell et al., 2019). U_j refers to the correlated effect (Manski, 1993): enterprises in the same group (here country) tend to behave similarly because they have similar individual characteristics or face similar institutional environments.

There is a direct connexion between our theoretical model and our econometric strategy. The following parameters γ_1 , γ_2 , δ_1 and ζ_1 will provide empirical support for testing, respectively H1, H3, H4.i and H5. i. H2, H4 and H5 will be tested using predicted probabilities following the methodology of Long (2009).

The model is classically identified through the non-linearity of the two equations. However, using relevant instrumental variables results in more robust estimations. Following Cainelli et al. (2020), we use various instruments, such as the availability of public financial support for eco-innovation (EI), as exclusion restrictions. Since we estimate our equation model using full information maximum likelihood, there is no directly equivalent test for the validity of the instruments as in limited information estimation to address endogeneity (e.g., control function or two-step estimators). We follow the suggestion by Roodman and Morduch (2014) to include the instruments in the outcome equation and test their significance as a way to assess whether their only impact on the outcome variable is mediated by the selection variable. Even in the case of non-exclusion restrictions, the model remains identified through its non-linearities (Roodman, 2011). Moreover, the estimations appear robust to various instrument exclusions (see Appendix 2 for alternative specifications).

To address the potential social desirability bias that may lead to the mismeasurement of the variables of interest (Roxas and Lindsay, 2012), we conduct a sensitivity analysis, as recommended by Blackwell et al. (2017). We test various scenarios, ranging from 10% to 50% of the observations being miscoded for each of the variables related to the measurement of production costs. As shown in Appendix 5, a reasonable upper limit of 30% of the observations being miscoded yields similar results. Scenarios with higher measurement errors can likely be ruled out, given that the Flash Eurobarometer survey design implements best practices to minimize social desirability bias (Roxas and Lindsay, 2012).

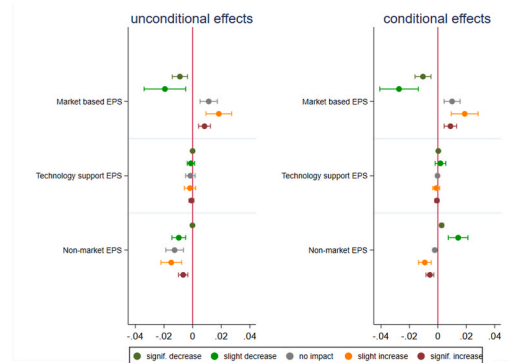
4. Results

The estimated parameters for all models are provided in Appendix 2. However, we only interpret the CRE model with age, market, technological public policies, and non-market public policies as instruments, as it is the best model according to the AIC and the Mundlak test. Given that the difference between the AIC values of the models is sufficiently large, the probability of incorrectly selecting a model different from the data

generation process (DGP) is relatively low (Burnham and Anderson, 2004). According to Akaike model weights, our benchmark model has an 83% probability of being the best among the competing models (see Appendix 3). All results are reported using *coeffplot* developed by Jann (2014). Conditional and unconditional marginal effects are available in Appendix 4. Our findings align with those of Rousselière et al. (2019) regarding the levers of eco-innovation (EI) adoption. Consistent with the literature, our results indicate that an increase in firm size (measured by the number of employees) and age is associated with a higher probability of adopting EI. Conversely, a decreasing or stable turnover correlates with a lower probability of EI adoption compared to a rising turnover. We also find that targeting the market towards consumers increases the likelihood of EI adoption, highlighting the importance of demand-side factors. Furthermore, the economic sector plays a role, with retail or service SMEs being less likely to adopt EI compared to manufacturing SMEs. This suggests that adoption mechanisms may vary depending on the type of EI and its relevance to the sector.

4.1. Investigating the various versions of Porter hypothesis: on the impact of environmental public policies on eco-innovation adoption and production costs

We investigate successively the three version of Porter hypothesis. Regarding the stronger version of Porter Hypothesis, Fig. 3 illustrates the effects of environmental policy stringency on the evolution of production costs, distinguishing between unconditional effects (left) and



Note: marginal effects with 90% level confidence interval

Fig. 3. Unconditional and Conditional Marginal Effects of Public Policies on Production Costs
Note: marginal effects with 90% level confidence interval.

conditional effects (right). Regardless of EI adoption, stricter market-based policies are associated with increased production costs, while technology support policies do not seem to influence cost evolution. Notably, while non-market-based policies may overall reduce the probability of EI adoption, they may contribute to decreasing production costs for SMEs that decide to implement EI actions. This suggests that stricter environmental policies based on non-market instruments may act as a filter, favoring more profitable EI initiatives.

Regarding the narrow version of Porter Hypothesis, the results presented in Fig. 4 indicate that the stringency of market-based environmental policy instruments and technology support policies does not significantly impact the probability of EI adoption, while the stringency of non-market-based environmental policy instruments decreases this probability. These results align with the findings of Hassan and Rousselière (2022), who observed that the stringency of market-based environmental policy instruments does not significantly impact EI in OECD countries. This is also consistent with Hassan et al. (2022), who found that increasing energy tax rates, a key market-based environmental policy instrument, can promote EI in the long term. The same reasoning applies to the technology support policies index, which includes support for renewable energy and public research and development expenditures. The negative impact of non-market-based environmental policy instruments on the probability of EI adoption may be consistent with literature suggesting that these tools offer little incentive for innovation, as there are no benefits exceeding facility-level quota obligations (Johnstone et al., 2010: 137). Moreover, Brunnermeier and Cohen (2003) found that increased government monitoring did not provide additional incentives to innovate. However, our results diverge from newer empirical studies that reveal a positive short-term impact of non-market-based environmental policy instruments on EI (Hassan and Rousselière, 2022). The discrepancy may be due to the outdated version of non-market-based environmental policy instruments used in Hassan and Rousselière (2022), which did not differentiate between technology support policies and those mandating emission limits and standards, whereas our research does.

To test the weak Porter Hypothesis, we conducted an additional test. Using the benchmark model, we computed the predicted probabilities of adoption for all quintiles of environmental policy stringency. A joint test ($\chi^2 = 5.65$, p -value = 0.227, with 4 degrees of freedom) does not reject the hypothesis that the predicted probabilities are equal. Thus, the weak Porter Hypothesis was not corroborated.

4.2. Investing the heterogeneous and indirect economic returns of EI

Our results reveal that the mechanisms linking EI adoption to changes in production costs depend on the type of EI (see Fig. 5). Most types of EI are associated with decreasing production costs, including selling scrap material to other enterprises, saving materials, using

renewable energy, and saving energy. However, designing sustainable products, recycling, minimizing waste, and saving water do not seem to significantly impact production costs. No type of EI is associated with increased production costs.

This overall impact is confirmed in Table 1, which reports the predicted probabilities of production cost evolution based on the number of EI implemented at the enterprise level. If a company implements at least one EI, the probabilities of observing significant and slight decreases in production costs are approximately 5.4% and 46%, respectively. These probabilities increase with the number of EI implemented.

The contextual effects assess how production costs for a SME change when other SMEs from the same country adopt EI (see Fig. 6). We find that within the national context, actions such as selling scrap material or saving water by other enterprises may lead to a slight increase in production costs for a given SME. In contrast, actions like designing sustainable products, saving materials, or saving energy appear to have a positive contextual effect, meaning they increase the probability that a SME will experience a decrease in production costs. The presence of both positive and negative contextual effects suggests that the economic mechanisms involved vary depending on the type of EI. Table 2 presents the combination of different types of EI. It indicates that the probability of reporting decreased production costs tends to decrease, while the probability of reporting increased production costs tends to increase, with the average number of EI implemented at the country level (classified by quintile).

5. Discussion

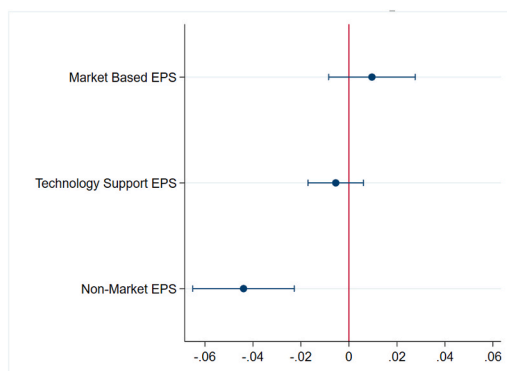
This paper makes contributions at two levels. First, at the methodological level, unlike previous studies that have examined these hypotheses either at the macroeconomic or microeconomic level, this study combines macro- and micro-level data to analyze the impact of environmental policy instruments on EI and their economic returns for SMEs. This approach considers the factors that drive the adoption of diverse EI strategies, while also controlling for endogeneity and sample selection bias. Second, at the empirical level, five hypotheses extending the traditional Porter Hypothesis were tested (see Table 3).

As in Cohen and Tubb (2018), we find mixed evidence for the various versions of Porter Hypothesis. Indeed, contrary to the findings of Prokop et al. (2023), the stringency of market-based environmental policies and technology support policies did not significantly influence the probability of EI adoption.

Interestingly, our findings show that while non-market-based policies generally reduce the probability of EI adoption, they may contribute to lowering production costs for a subset of SMEs that nonetheless decide to implement EI. Compliance with emissions standards, a key component of non-market-based policies, necessitates more efficient use of materials, the adoption of energy-efficient technologies, and increased recycling, which can reduce the need for new raw materials and lower overall production costs. Furthermore, companies that adhere to emissions standards can enhance their brand reputation, attract environmentally conscious consumers, and open up new markets, particularly in regions with strict environmental regulations, thereby increasing sales and reducing per-unit production costs (Gálvez-Sánchez et al., 2024).

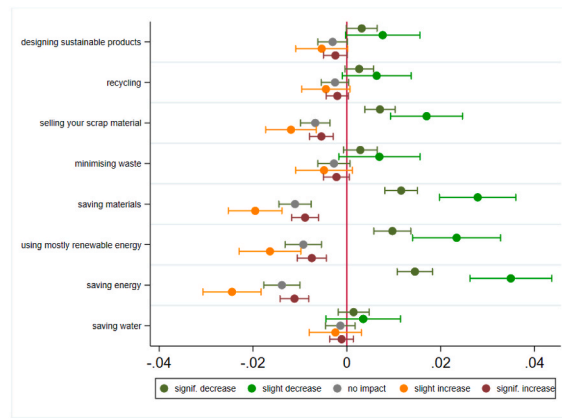
Based on these results, this paper demonstrates that the Porter Hypothesis's weak version is not valid for European SMEs, while the strong version is supported only for non-market-based environmental policy instruments. The narrow version of the Porter Hypothesis is in part validated.

Other findings relate to the impact of EI on production costs. Our results indicate that the impact on production costs varies depending on the type of EI implemented and is also influenced by contextual effects at the national level. In contrast to Latupeirissa and Adhariani (2020), who found no impact of EI on company performance, our study reveals that specific actions—such as selling scrap materials to other enterprises,



Note: Marginal effects with a 90% confidence interval.

Fig. 4. Impact of Public Policies on Eco-Innovation Adoption
Note: Marginal effects with a 90% confidence interval.



Note: Marginal effects with a 90% confidence interval. For instance, the implementation of energy-saving actions significantly increases the likelihood that a SME will report a slight decrease in production costs.

Fig. 5. Direct Effects of the Various Types of Eco-Innovation on Production Costs

Note: Marginal effects with a 90% confidence interval. For instance, the implementation of energy-saving actions significantly increases the likelihood that a SME will report a slight decrease in production costs.

Table 1

Predicted probabilities of production cost evolution based on the number of EI implemented at the enterprise level.

	Production costs				
	signif decrease	slight decrease	no impact	slight increase	signif increase
at least one EI	0.054*** (0.003)	0.460*** (0.008)	0.241*** (0.005)	0.183*** (0.005)	0.062*** (0.006)
one EI	0.033*** (0.002)	0.400*** (0.010)	0.257*** (0.005)	0.222*** (0.006)	0.088*** (0.009)
two EI	0.041*** (0.002)	0.426*** (0.009)	0.251*** (0.005)	0.206*** (0.006)	0.077*** (0.007)
three EI	0.045*** (0.002)	0.438*** (0.008)	0.249*** (0.005)	0.198*** (0.005)	0.071*** (0.007)
four EI	0.053*** (0.003)	0.463*** (0.008)	0.242*** (0.005)	0.181*** (0.005)	0.060*** (0.006)
five EI	0.059*** (0.003)	0.475*** (0.008)	0.238*** (0.004)	0.173*** (0.005)	0.056*** (0.006)
six EI	0.068*** (0.004)	0.498*** (0.008)	0.229*** (0.004)	0.158*** (0.005)	0.047*** (0.005)
seven EI	0.075*** (0.004)	0.510*** (0.009)	0.223*** (0.005)	0.148*** (0.006)	0.042*** (0.005)
eight EI	0.091*** (0.006)	0.533*** (0.009)	0.211*** (0.005)	0.131*** (0.006)	0.034*** (0.004)

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

saving materials, using renewable energy, or conserving energy—are associated with decreased production costs. This suggests that promoting these actions could be bolstered by communicating the associated economic incentives more effectively. Public policymakers and private economic partners could benefit from organizing exchange and feedback workshops to discuss the link between these actions and changes in cost structures for companies already engaged in ecological transitions. However, we also find that certain EIs, such as sustainable product design, recycling strategies, and waste and water consumption reduction, do not significantly impact production costs. These specific actions may require alternative forms of public intervention that account for the challenges posed by transition costs.

Regarding the contextual effects of EI adoption by other enterprises on the costs of implementing EI within a given enterprise, our study identifies two opposing mechanisms, reflecting processes of cooperation and competition. SMEs that implement EIs, such as sustainable product design or material and energy conservation, are likely to observe decreased production costs if other SMEs in the region have also adopted

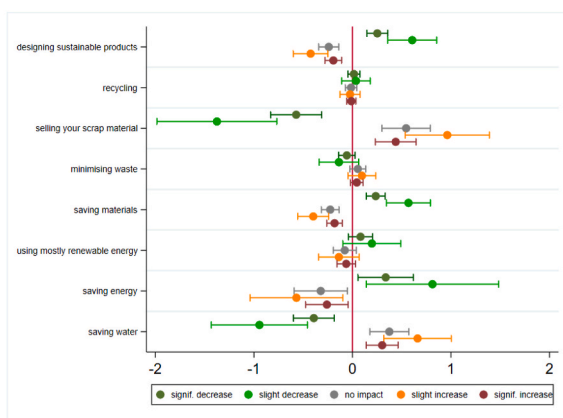
similar actions. This finding suggests the presence of knowledge externalities, whereby the outcomes of a given EI can benefit all partners within the same territory. This is consistent with the results of Alcalde-Heras and Carrillo-Carrillo (2023). Conversely, some actions, such as selling scrap, exhibit negative effects, which we attribute to competitive dynamics in the coproducts market. When the number of enterprises selling their coproducts increases, it may lead to an oversupply situation (Suh et al., 2010), where the quantity of coproducts exceeds market demand, thereby reducing their price.

The coexistence of both cooperation and competition mechanisms underscores the importance of integrated territorial approaches. Beyond the mere adoption of EI, it is in the interest of public policymakers to simultaneously focus on all levers related to the circular economy by promoting schemes that foster cooperation and proximity in supply strategies, eco-design, and technological processes (e.g., creation of innovation laboratories, networking devices). The presence of yardstick competition effects further justifies this territorial approach, as it highlights the need to organize and coordinate the exchange of goods that may be waste for some firms and raw materials for others (Gigli et al., 2019).

6. Conclusion

This research pursued three primary objectives. First, it aimed to estimate the impact of environmental policy instruments on environmental innovation (EI) and production costs for SMEs in Europe by integrating both macro and micro data. Additionally, to gain a comprehensive understanding of EI determinants, we controlled for various factors that influence engagement in EI strategies. Second, the study examined the specific impact of different types of EI on production costs. Finally, it explored the contextual effects of EI adoption by other enterprises on the implementation costs for a given enterprise. To achieve these objectives, we employed a mixed ordered probit model with correlated random effects and sample selection to estimate the regression parameters and determine the most suitable model. This paper contributes to the existing literature on EI by testing and extending the Porter Hypothesis. We demonstrate that the impact on production costs varies depending on the type of EI implemented and is also shaped by contextual effects at the national level. Furthermore, our findings highlight that while non-market-based policies may generally reduce the likelihood of adopting EI, they can contribute to lower production costs for those SMEs that do choose to implement EI.

There are, however, some limitations to this research. First, the



Marginal effects with a 90% confidence interval. For example, when other SMEs in a given European country implement water-saving actions, this significantly increases the likelihood that a respondent will report a slight increase in production costs.

Fig. 6. Contextual Effects of the Various Types of Eco-Innovation on Production Costs

Marginal effects with a 90% confidence interval. For example, when other SMEs in a given European country implement water-saving actions, this significantly increases the likelihood that a respondent will report a slight increase in production costs.

Table 2

Predicted probabilities of production cost evolution for the average number of EI activities implemented at the country level.

		Production costs				
		signif decrease	slight decrease	no impact	slight increase	signif increase
At least one EI	1st Quintile of countries	0.070*** (0.009)	0.462*** (0.020)	0.175*** (0.007)	0.092*** (0.008)	0.016*** (0.003)
	2nd Quintile	0.053*** (0.006)	0.441*** (0.017)	0.204*** (0.004)	0.126*** (0.006)	0.027*** (0.004)
	3rd Quintile	0.070*** (0.006)	0.478*** (0.012)	0.203*** (0.004)	0.122*** (0.005)	0.026*** (0.003)
	4th Quintile	0.041*** (0.004)	0.417*** (0.015)	0.232*** (0.004)	0.169*** (0.006)	0.047*** (0.005)
	5th Quintile of countries	0.044*** (0.004)	0.436*** (0.013)	0.236*** (0.005)	0.170*** (0.006)	0.047*** (0.005)
Number of EI	1st Quintile of countries	0.048*** (0.008)	0.416*** (0.028)	0.184*** (0.008)	0.105*** (0.009)	0.019*** (0.004)
	2nd Quintile	0.065*** (0.006)	0.466*** (0.015)	0.193*** (0.004)	0.110*** (0.005)	0.021*** (0.003)
	3rd Quintile	0.068*** (0.006)	0.468*** (0.013)	0.205*** (0.005)	0.128*** (0.005)	0.029*** (0.004)
	4th Quintile	0.049*** (0.004)	0.445*** (0.013)	0.223*** (0.004)	0.148*** (0.005)	0.036*** (0.004)
	5th Quintile of countries	0.040*** (0.004)	0.419*** (0.013)	0.241*** (0.005)	0.183*** (0.006)	0.055*** (0.005)

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

analysis is restricted to a two-year period due to data availability. Second, the study focuses exclusively on European countries. Future research could address these limitations by extending the study over a longer period and expanding the scope to include BRICS countries and developing economies, as data becomes available. Our database does not allow us to investigate the crucial role of human capital on green innovation (Musolesi et al., 2024). Semi-parametric analysis may also be relevant to underline smooth heterogeneous effects. Finally, we do not consider indirect effects on performance at the international level, as environmental policies may also seem to promote export dynamics (Costantini and Mazzanti, 2012). Therefore, our results can be considered conservative as they may underestimate some economic benefits (such as increased export profits) for part of the SME population studied.

The results of this study have significant policy implications for both policymakers and SMEs. For policymakers, the findings suggest that the double-dividend hypothesis is not universally applicable; its validity depends on the type of innovation adopted, at least in the short term. To address this, public policy plays a crucial role and should be designed to

encourage practices that yield a double dividend in the medium to long term. We recommend that public policies be further refined and tailored to different types of EI and to the specific characteristics of firms in order to enhance both environmental and economic performance. For SMEs, our study indicates that specific actions, such as selling scrap materials to other enterprises, conserving materials, using renewable energy, or improving energy efficiency, are associated with lower production costs. SMEs can thus increase the implementation of these actions with the goal of reducing costs and boosting profitability.

CRedit authorship contribution statement

Samira Rousselière: Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Thomas Coisson:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Mahmoud Hassan:** Writing – review & editing, Writing – original draft,

Table 3
Tests of hypothesis.

Hypothesis	Test	Corroboration
H1 Porter Strong Hypothesis	Marginal effect of EPS on production costs	Partially supported: Negative impact of non market based EPS on production costs Positive impact of market-based EPS on production costs
H2 Porter Weak Hypothesis	Joint test of differences for predicted probabilities of EI adoption depending on various quintile of EPS	Null results
H3a & H3b Porter Narrow Hypothesis	Marginal effect of EPS components on the adoption of EI	Partially supported: Negative impact of non market based EPS on EI adoption No impact of other instruments
H4 EI show heterogeneous profitability (H4 and H4.1 to H4.8)	H4: Predicted probabilities of production cost evolution depending on number of EI H4.1 to H4.8: Marginal effects of EI on production costs	Supported Supported: Average decrease in production costs for some EIs
H5 The development of EI is impacted by the development of EI by other companies (H5 and H5.1 to H5.8)	H5: Predicted probabilities of production cost evolution depending on average number of EI at the country level (quintiles) H5.1 to H5.8: Contextual effects of EI on production costs	Supported Supported: Average increase in production costs for some EIs

Methodology, Data curation. **Anne Musson**: Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Damien Rousselière**: Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jclepro.2024.144329>.

Data availability

The authors do not have permission to share data.

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