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On the Empirical Relationship between Environmental Regulation and Productivity

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To my family

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Abstract

Our work aims at investigating the impact that the implementation of the EU ETS has had on industry-level growth in a panel of EU countries along with Japan and the United States. The use of this instrument should allow us to test the strong version of the Porter hypothesis by using a market-based regulation meeting the economic efficiency and soundness criteria. The implementation of this market for carbon has led to a short-term increase in the productivity of labor. The effect however reversed as European regulators decided to reduce the amount of allowances available to firms. In the longer term as they adapted to the new conditions, a boost in productivity is witnessed, with labor productivity increasing at the industry level.

Contents

Introduction

According to Porter (1991) well-designed environmental policies have the potential to achieve a double dividend: more severe and stricter environmental regulation should have a positive effect on firms' performance by stimulating innovations and the development of new technologies to comply with the regulation. The cost of compliance, therefore, is believed to be offset, partially or even fully, by the innovation triggered by the policy action. The effect resulting from the additional burden for firms, created by the stringent environmental regulation, is believed to be smaller than the impact of the incentives for innovation, efficiency improvements and within-firms reallocation, forces which go in the direction of higher productivity. This is due to the fact that pollution is believed to be a manifestation of economic waste, involving incomplete utilization of resources. Regulations aimed at reducing pollution therefore improve resource utilization within firms. This hypothesis is obviously controversial and much debate has sprung after its initial formulation. Standard neoclassical models suggest no 'low-hanging fruits' are available for firms since they are perfectly rational and reap every profit-increasing opportunity. The theoretical justification of the Porter hypothesis therefore is based mainly on shortcomings of the neoclassical theory: when we consider firms as either not always being profit-maximizing or when we take into consideration market failures, then we are able to show the feasibility of the Porter hypothesis without the need to call for too extreme assumptions. The theoretical debate on the Porter hypothesis has been, however, much less rich than its empirical counterpart. Many studies, in fact, have tried to empirically test the validity of the Porter hypothesis but evidence on it is rather weak. Empirical results are in fact ambiguous at best, with the first studies published on the topic attributing the slowdown of productivity in the United States in the 1970s to the environmental policies enacted in the country in the same period. More recently, however, studies have suggested that stricter environmental regulation may result in a short-term decrease in productivity but in the longer term the effect reverses and becomes positive. Moreover, both empirically and theoretically, not all types of regulations are believed to have the same effect. It is those policies which make firms internalize their cost of pollution while making them retain the flexibility to overcome the new requirements which are believed to be productivity-enhancing. The standard and command-and-control approaches are instead believed not to have the same effect and hence do not result in double dividends.

In 1997, the Kyoto Protocol established for the first time legally-binding emissions reduction targets. The European Union took an active role in shaping how European countries were to achieve these results and hence implemented a market for carbon called Emissions Trading System (the EU ETS). The EU ETS, is therefore a market-based instrument, which as per the Porter hypothesis, should lead to an increase in the productivity of labor. In this work we focus on the so-called 'strong' version of the Porter hypothesis, claiming that more stringent environmental regulation leads to increases in productivity if it is well-designed. We believe the EU ETS is a good instrument to test the validity of the Porter hypothesis given that it meets the economic efficiency and soundness criteria: it makes firms sensitive to the amount they pollute by attaching a price to that pollution and hence it stimulates them to innovate and adopt new technologies. In Section 1 we provide an overview of the most relevant empirical literature of both the 'strong' version of the Porter hypothesis and its 'weak' version, which posits a positive effect on R&D of more stringent environmental regulation. Section 2 reviews the main theoretical contributions that have been laid out and which try to justify the Porter hypothesis by deriving situations in which it is reasonable to believe that stricter environmental policies lead not only to better environmental outcomes but also to productivity enhancements. Section 3 presents our empirical methodology and details about the data we have used. Section 4 provides our main results. The final section concludes.

1 Literature review

The theoretical effect of environmental regulation on the innovativeness and competitiveness of firms is unclear. The common conception among economists was that oppressive government regulation, and in particular increasing environmental regulations, was one key factor in determining the poor economic performance of the US in the 1970s (see Christainsen and Haveman, 1982 for a review).

A different stance is taken by Porter and the so-called Porter hypothesis: the claim is that tougher environmental regulation can provide an incentive for firms to develop new and less costly ways of reducing pollution or even revolutionizing entirely their method of production so that the elimination of the pollutant can be achieved *while* reducing costs. This claim would imply that the policies promoted in order to reach a greener, cleaner, carbon-neutral world can potentially bring about also an increase in profitability as "innovation offsets can exceed the cost of compliance" (Porter, 1991; Porter and van der Linde, 1995). A consequence of the Porter hypothesis is that environmental regulation is good not only for society, but also for firms themselves, whose private benefits are increased due to the enhanced productivity brought about by innovation. The evidence presented by the authors is mainly a collection of case studies in which the firms seized environmental regulation as an opportunity not only to comply with it but also to increase the efficiency of their production processes or improve the quality of their products by investing in technologies. The typical example illustrated is that of the Japanese regulations aimed at controlling pollution. In the 1970s the country was considerably surpassing the United States in terms of growth rates of GNP and productivity though having tougher regulations in place [1].

On the opposite hand, other authors view environmental regulation as a con-

[1] For instance, the World Bank registers an average annual growth rate of GNP of 4.52% for Japan and 3.25% for the United States in the period 1971-1980. At the same time, as noted in Mackey and Hart (1993), Japan had stricter and better-enforced environmental laws.

straint to firms' profit-maximizing behavior. Palmer, Oates and Portney (1995) challenge Porter's assertion that regulation overcomes organizational inertia by providing the firms with incentives which the competitive market fails to deliver. Firms, instead, are obliged by the new regulation to devote part of their resources to pollution abatement or in any case to uses which are neither productive nor profit increasing so that, eventually, environmental policies hinder the possibility of firms to pursue profit-increasing opportunities.

Empirical studies aimed at examining the relationship described by the Porter hypothesis fall in two broad categories: those focusing on the effect of environmental regulation on firm's productivity- delving into the analysis of the 'strong' version of the Porter hypothesis; and those considering the relationship between environmental regulation and innovation- testing the 'weak' version of the Porter hypothesis. A third stream of studies investigates the 'narrow' version of the Porter hypothesis, which posits the existence of stronger benefits in terms of productivity under some types of environmental regulations. Overall, these studies use a wide range of measures for environmental policy stringency. The proxies most frequently used in cross-country analyses or to measure the impact of a number of policies include pollution abatement expenditures, survey-based policy perceptions, environmental treaties signed or even green voting records. Some others better capture the causal relationship between environmental regulation and innovation or competitiveness by focusing on the introduction, or significant change, of some particular policy, at the expense, nonetheless, of generality.

A comprehensive review can be found in Kozluk and Zipperer (2014), assessing the main empirical studies at firm-, industry- and macroeconomic level which have been conducted with respect to both the 'strong' and 'weak' version of the Porter hypothesis.

1.1 Environmental regulations and productivity

The first studies, which focused on explaining the US productivity slowdown of the 1970s, found a negative effect of environmental regulations on productivity growth but failed to address simultaneity issues, meaning that factors other than environmental policies may have been the true determinants of the phenomenon: more recent works, which have taken into account simultaneity problems, have different findings: the effect on productivity is in fact either nil or even positive, though the same phenomenon is analyzed. Generally speaking, empirical evidence regarding the effects on productivity is ambiguous. At the industry level, evidence is inconclusive on the significance and direction of the effect, but this may be due to the specificity of the studies: the vast majority of them focuses on particular countries, industries, or environmental laws. A negative correlation is usually found for older studies: Gray (1987) finds strong and significant negative effects, however they disappear when we include controls or eliminate the outliers; Barbera and McConnell (1990) limit their analysis to five industries and are unable to control for industry-effects; Dufour et al. (1998) do control for industry-effects and find a significant negative result but their generality is questionable given the very limited sample. More recent studies, though still suffering from lack of generality, find nil or positive effects: Hamamoto (2006) analyses five Japanese manufacturing sectors and virtually calculates the effect of induced environmental R&D on productivity, Yang et al. (2012) apply the methodology developed by Hamamoto to the Taiwanese manufacturing sector, and Lanoie et al. (2008) find short-run negative effects of environmental regulation for Québec but in the long-run the sign is reversed. Albrizio et al. (2017) conduct the most comprehensive study in terms of countries and policies, as they use OECD data on productivity and a newly constructed Environmental Policy Stringency index- developed by Botta and Kozluk (2014)- and find short-run positive effects for industry-level productivity growth especially in the most technologically-advanced countries: the farther from the global productivity frontier, the more lenient the effects until they become insignificant.

At the firm- and plant-level the effects are overall negative but not very robust, and tend to compare productivity growth between regulated and unregulated plants. Smith and Sims (1985) find negative while Berman and Bui (2001) positive but insignificant effects using fixed-effect or difference-in-difference approaches, however none is able to control for the different characteristics of the groups. Other studies include Becker (2011) finding no effect of environmental regulation on labor productivity levels in a broad sample of plants and Greenstone et al. (2012) whose results indicate that the sign of the effect of the regulation may depend on the pollutant being restricted: ozone and particulates emission regulations are found to have negative effects, sulphur dioxide emission have no significant effect and carbon monoxide regulations induce productivity increases; though the authors fail to deliver an explanation for the phenomenon. None of the studies controls for spill overs across firms.

Empirical evidence at the macroeconomic level is very limited and inconclusive for the most part. In fact, most of the studies suffer from both data and identification problems and find contradictory results. Surprisingly, even when using the same proxy for environmental policy stringency the sign of the effect may not be univocal, as when using a dummy for the ratification of the UNFCCC [2]: Yörük and Zaim (2005) find positive while Wu and Wang (2008) negative effects- though, the explanation may rest in the different samples of countries, OECD for the former and APEC for the latter.

1.2 Environmental regulations and competitiveness

The other line of research focuses on the 'weak' version of the Porter hypothesis, and uses as a proxy for innovation either input- or output-based measures. In the

[2]The United Nations Framework Convention on Climate Change signed in 1992 and aimed at reducing GHG emissions, regarded as the main determinants of global warming.

first strand, we see that R&D expenditures are the most frequently used measure of innovation, while the number of patents are used in the latter case. The trend is one of positive effects of environmental regulation on innovation and this could be seen as somewhat contrasting the more ambiguous results of the ‘strong’ version of the Porter hypothesis. However, one can note that both proxies are less than perfectly related to the overall increase in innovative activity and the relationship is even more feeble for the resulting improvements in productivity. We can also note that environmental R&D may be increased, following stricter environmental regulation, at the expense of general R&D.

In particular, at the industry level, Jaffe and Palmer (1997) find positive effects on R&D expenditures but fail to find any effect on actual patents, even though this may be due to the fact that the incremental R&D induced by regulation is unproductive or produces results that help with regulatory compliance but do not appear as patentable inventions. Hamamoto (2006) also finds positive effects on R&D spending. Kneller and Manderson (2012) find a positive relation between policy stringency and environmentally-related R&D, but not total R&D.

At the plant- and firm-level fairly strong effects are found on the environmental R&D spending by Yang et al. (2012). Arimura et al. (2007) and Lanoie et al. (2011) use microeconometric techniques to analyze the simulated effects of stringent environmental policies on environmental R&D spending and find that strict environmental policies, measured using perceived policy stringency, flexible environmental instruments, and environmental accounting systems, play a positive role and do indeed stimulate environmental R&D.

The macroeconomic level has not been subject to much investigation and the few empirical studies find only some weak evidence such as in De Vries and Withagen (2005).

Overall, these studies are unable to control for spill-over effects across industries and firms, meaning that they cannot capture innovation which is spur in sectors other than those which are directly affected by the regulation and which can lead to general-purpose technologies. Moreover, these studies may underestimate the effect of environmental innovation by looking only at domestic effects.

1.3 Conclusions

We have insofar analyzed the empirical evidence regarding the Porter hypothesis and found that the existing literature is mostly inconclusive as to what the sign of the effect of environmental regulation on productivity is, while somewhat more robust results are found linking positively environmental regulation to increases in innovation.

We are now moving on to the definition of our empirical model and test, which will allow us to examine the relationship between productivity and environmental regulation. To measure the latter, we will need to use a policy meeting the economic efficiency and soundness criteria in order to be truly able to give meaningful results for a test of the Porter hypothesis. Before doing that, however, we will review theoretical models which can justify the very economic existence and feasibility of the Porter hypothesis that firms subject to stricter environmental regulations can offset the increased regulatory costs through innovation and increase their productivity.

2 Theoretical models

In our analysis we want to investigate the relationship between environmental regulations and the possibility that it leads to a win-win situation so that not only is pollution reduced as a result of the implementation of the new policy but labor productivity is also fostered. As we have seen in the preceding section, the empirical evidence for this is somewhat ambiguous, even though not all tests are properly designed or even capable of proving or disproving the Porter hypothesis. In this section, before introducing our empirical model, we are going to have an overview of the main theoretical models, which can justify from a conceptual viewpoint why a free lunch might arise. In doing so, we will have to relax some of the main assumptions of neoclassical economic rationality, in particular the assumption that profit-maximizing opportunities are always reaped by the firm.

The theoretical discussion on the validity of the Porter hypothesis is much less rich than its empirical counterpart. As already stated, the main argument brought by Porter and van der Linde (1995) is that a more stringent environmental regulation which is incentive-based can eventually increase the firm's competitiveness and this may in the long-run outweigh the private costs that are incurred due to the new regulation. The evidence is mainly anecdotal.

The proposition was met with skepticism: the neoclassical theory of the firm posits that since those entities are profit-maximizing, the firm must have already realized all profit-increasing opportunities and therefore the new, stricter, environmental regulation can only impose an additional constraint and burden on its operations. This means that no $10 bills can be found lying on the ground ready to be taken up. The consequence is that, in rational economic modelling, environmental regulation will only impose additional costs on domestic firms, as it is not needed to trigger innovation in the first place. This view is shared, among others, by McGuire (1982), Yohe (1979) and Siebert (1977). None of these authors, however, take into account the possibility that innovation may spring from stricter regulation. Palmer, Oates and Portney (1995), instead, do, but they restrict the phenomenon by claiming that it is very rare in practice.

On the contrary, another stream of economists, which can be considered as part of a 'revisionist' school [3], are constructing theoretical models which can explain the Porter hypothesis without having to rely on unrealistic or too-specific assumptions for the advantages it proposes to become possible. We can distinguish, following Ambec et al. (2011), two main approaches: the first departs from the assumption of profit-maximizing firms, in line with the rising influence of organizational and behavioral economic literature. This approach sees the rationality of the firm as driven by the manager, whose motivations may depart from profit-maximization. We can see that, for example, in Ambec and Barla (2002) the manager is resistant to any costly change and has present-biased preferences, while in Gabel and Sinclair-Desgagné (1999) he is rationally bounded. A second stream of papers, instead, does not drop the profit-maximization assumption but considers market failures. Such an approach is taken up, for example, in Mohr (2002) which considers a coordination failure with technological spillover. With the view of relying on technological spillovers with an upstream market for innovation, Xepapadeas and de Zeeuw (1999) analyze the impact of environmental regulations on the underlying dynamic of capital.

2.1 Environmental regulation and organizational failures

One of the main arguments that has been brought and developed to justify why environmental regulation should result in a free lunch for the firm affected by the policy is that of organizational failures.

In the original works by Porter and his colleagues (Porter, 1991; Porter and

[3] We take this terminology from Alpay (2001) which differentiates and distinguishes between a 'conventional' school, characterized by the refusal of the possibility of profit-increasing opportunities being reaped only after a more stringent environmental regulation is implemented; and a 'revisionist' school, which accepts the Porter hypothesis, though with exceptions and limitations.

van der Linde, 1995; Etsy and Porter 1998), they argue that the reason why the Porter hypothesis is valid is that firms do not face a static framework of optimization, but rather a dynamic competition process. In this new conceptual set, companies are inexperienced in facing environmental problems, and lack creativity in dealing with environmental issues. This incomplete information problems and organizational inertia that characterize the firm, result in the possibility of new technological innovation being influenced by the implementation of a properly designed regulation. The main ways in which the policy does it is by signalling the resource inefficiencies and possibilities for technological improvements, by raising awareness for improvement potential, and by reducing the uncertainty of the net paybacks from investments.

A formal model which encompasses this idea is developed by Gabel and Sinclair-Desgagné (1999) and Sinclair-Desgagné (1999). The two authors, against the neoclassical economic rationality of the firms, signal the inconsistency of seeing markets as capable of imperfectibility but firms as uniquely and inherently perfect. They emphasize how, in this context of analysis, organizational failures are of importance: their manifestation is in fact unachieved profit potential- what they call 'low-hanging fruits', capable of being reaped once changes in the system make it profitable to do so. They model the firm including the organization's need to control its agents' behavior- the management and employees of the company- using internal management systems and policies, and therefore by modifying the neoclassical model. This leads them to explain some organizational failures. The reason why firms are subject to such inefficiencies is that they «do not act as single-minded omniscient entities» (Sinclair-Desgagné, 1999) and this justifies the theoretical existence of a win-win situation, not supported by neoclassical-economics models. The firm is seen as a principal linked to its agents by a network of both systems and procedures, which provide stability to the organization, co-ordinate and control agents' behavior, and economize on the time and attention available. These systems are, therefore, a constraint on the firm's objective of profit maximization because they are designed to minimize operating costs but they are also rigid: many of the decisions a firm takes are standardized, leading to mismatches between the actual events and the standardized types.

The inefficiencies within the firm are thus revealed thanks to the stringent regulation that is passed. The existence of these internal failures is logically most likely whenever the firm is far from the efficiency frontier. For firms which instead are closer to it, the cost of compliance is light, and cheap innovations are unlikely to show up. The change in the system, they argue, is obviously disruptive, revolutionary and costly. Firms may be reluctant to innovate but eventually they will be lead to a radical rethinking which will prompt a reoptimization of the procedures: the firm experiences an absolute cost reduction after it has incurred not only the increased compliance costs but also the cost of the management system restructuring.

A question, in the model, remains: what type of regulation is most likely to rectify the organizational inefficiencies given that quasi-regulatory firm-internal ways of coping with them exist? We know in fact that such tools as contract design, different choices of allocation of authority and task allocation decisions are all designed to diminish the existence of such opportunities and therefore the authors, aware of such issues, remain open to debate and encourage further research in the topic.

Another model which substantiates the Porter hypothesis by looking at the role played by agency costs and the internal organization of the firm can be found in Ambec and Barla (2002). The Porter hypothesis's result is presented by comparing the outcomes of two games- a regulated and an unregulated one.

The assumption made by the authors is that less polluting technologies are also more productive. In the context developed, productivity is the private information of the manager so that the firm must offer an informational rent to reward truthful reporting of high productivity. The reason why regulation helps the firm is that while the regulator can commit to distort production to the social efficient level, the firm cannot. This implies that for the division manager, reporting unproductive and polluting technologies becomes less attractive than it was before the policy was undertaken. Thanks to the fact that output is distorted to the social efficient level whenever an environmentally damaging technology is in place, the newly implemented regulation is able to: (i) reduce the informational rents; and (ii) decrease the surplus privately obtained when the technology used is the polluting one. Hence, the authors are able to show an unambiguous positive impact on the level of investments in R&D following the implementation of a new policy because of the fact that the marginal benefit to investment increases.

The effect on the profitability is, however, ambiguous and to get to an unambiguous net positive effect some conditions need to be met so that the authors show how the Porter hypothesis is more likely to hold whenever three conditions are satisfied. The first is that there must be a high likelihood of obtaining a more productive and cleaner technology. The second is that the marginal productivity gain that is induced by the newer and more productive technology is high. The third is that the regulation must have a smaller impact on the profit that is generated by the more polluting technology than the effect it has on the output decision. In the end this implies that, when the previous conditions are met, environmental regulation is capable not only of increasing the investment in R&D by firms but also their expected profits. The regulation which is taken into account by the authors is one like an emission permits system: they, in fact, consider a benevolent regulator who fixes an upper bound on the environmental damage inflicted by the firm, which, as we saw, can entail limiting output. The regulator in this context tries to maximize social welfare, which they define as total private surplus minus environmental damage. The authors conclude by noting how different types of regulation could have different effects: whenever, for example, we consider other types of policies such as end-of-pipe treatments or even Pigouvian taxes, we are effectively increasing the costs in equilibrium so that, even though the informational-rent decreasing effect is still present, the impact on the profits generated by the more polluting technology is more severe and eventually the firm's expected pay-off is less likely to be increased after the regulation is implemented.

2.2 Environmental regulation as a new revenue source

An interesting discussion and model, linking stricter environmental regulation with increased innovation and competitiveness of the firms is offered in Alpay (2001). The analysis is conducted in an economy where two Cournot oligopolists produce a good and its process of production is pollution-emitting, so that emissions are proportional to output. The author conducts the analysis taking into consideration the effects of the tightening of an emission trading system, used by the environmental agency to control the aggregate emission level.

The objective of the firm is, as usual, to maximize the profits, and in doing so it must choose output and abatement level. Constructing the reaction function of each (symmetric) oligopolist, we can see that the optimal quantity produced in this context will be a negative function of the average emission rate and of the permit price, a sound result given that pollution is proportional to output and this externality must be monetarily compensated. We can see that in calculating the profits of the firm, we will have to take into consideration the possibility for the regulated firm to resell part of its permits through the permit market: this implies that the profits of a regulated firm may be higher than the profits of an unregulated firm. This means that when environmental regulation is carried out through an emission trading system higher profits are possible for the firms that are subject to the regulation than those that are not, given that it can earn enough revenues through the permit market.

The author also considers the effect of a policy tightening. In this case, the options available are for the incumbents to either maintain the *status quo* or to innovate. Four cases are therefore considered: when none of the firms innovates, when just one of the two does, and when both do. Innovation is carried out by increasing investments in R&D in order to try to obtain a better abatement or production technology.

It is easy to see that in case one, when none of the firms decides to make additional investments on R&D and instead both decide to stick to current production processes and technologies, the returns are expected to be smaller as the new, more stringent regulation is put in place. As there is now a lower number of permits available, their price will increase and each firm will produce less. This, however, has an ambiguous impact on the profit levels: as we said, in fact, it is true that higher permit prices mean lower quantities being produced, but it is also true that the firm still has the possibility to resell the permits at a now higher price. The author, therefore, concludes that also in this case it is conceivable for profits to increase following a tightening in the environmental regulation even if the firms decide not to innovate.

In the second and third cases, when only one of the two firms engages in additional R&D and the other sticks to the old technology, the results are even more relevant. Once profits expressions are derived, the author can show how the innovating firm is able to increase its market share and to undertake a higher abatement as compared to the one which does not innovate. The innovating firm, moreover, is shown to have higher profits than the non-innovating firm also thanks to the fact that the 'expected' abatement technology, better than the older one, brings about the possibility for a larger permit revenue. The fact that a better technology is, however, only probable and not certain entails that the interest in investing in R&D is subject to firms' private evaluation. Notwithstanding, we can generally say that as the permit prices increase, the expected returns are more likely to outweigh the cost of innovation and therefore more firms are expected to take part in R&D investments.

In the final case, the fourth one, there is the consideration of the situation in which both firms decide to innovate. Compared to the preceding one, we can see that although both firms benefit from increased profits resulting from the decision to undertake innovation, the competitiveness of the single firm is more likely to improve when it is the only one that innovates.

The author concludes by examining a channel not previously taken into account in other works: an explicit consideration of the impact of the new regulation on the demand side is, in fact, carried out. The conclusion arrived at is that whenever consumers value the environmentally-friendly good more than the other one, then an increase in the competitiveness of the innovating firm is to be expected.

2.3 Environmental regulation and external economies

In a general equilibrium framework, Mohr (2002) is able to show the validity of the Porter hypothesis by linking it to the presence of external economies of scale. For this to be the case, he allows the productivity of any one agent to depend on the cumulative industry experience with a particular technology. This means that as experience increases, output increases, and the increment in experience is given by the previous amount of labor that has been dedicated over time to the use of a particular technology.

In this model, the author assumes competitive behavior and constant returns to scale over labor and waste produced so that the number of firms present in the economy does not matter. Moreover, the author assumes two distortion effects in the economy: an environmental externality, treated cumulatively by each individual as exogenous given that no agent can measurably change aggregate waste, and spillover in production. Finally, although individual agents do not take into account the effects of their production on environmental quality and so produce until the marginal product of waste is equal to zero, reaching at each period the maximum level of waste, there is also a social planner who, instead, is concerned with environmental degradation and has to solve the problem of equating the marginal disutility of environmental degradation to the marginal utility of consumption. This means that the social planner will allow production to increase until the benefits of increased consumption equal the damage socially inflicted, which is a result of the fact that pollution has a social cost. It is easy to see, in this case, that the optimal policy response would be to impose a tax to reduce emissions. The size of the tax would be equal to the marginal disutility of consumption so that production would stop not when the marginal product of waste is zero but when it is equal to the marginal utility cost of aggregate waste. Hence we initially have a traditional framework: an increased environmental tax imposes a compliance cost which can be measured by lost productivity.

The result previously obtained, however, is arrived at because all agents are constrained to use the same technology. Let us, now, introduce a 'cleaner' technology, so that, for a given level of experience, it can produce the same amount of output using less waste. We assume that initially everyone has the more polluting technology and that switching technology has some short-term costs so that the productivity of the new technology is temporarily lower than the productivity of the older technology because of the fact that aggregate experience on it is higher than on the newly-adopted technology. This means that everyone would like others to adopt the technology first so that they are willing to switch, given that others have previously done so. The agents have therefore a second-mover advantage: the existence of external economies of scale prevents any one individual firm from applying the 'cleaner' technology. In this context, the government can introduce a regulation favoring or requiring the adoption of the new technology so that environmental policy is able to both improve environmental quality and, once enough experience has built up, to increase productivity. This result, consistent both with the Porter hypothesis and with the empirical data showing that environmental policies are able to positively influence productivity with a time lag, is, however, subject to the very strong assumption that more productive but unused technologies must be available. Moreover, the policy is able to lead to productivity-enhancing results only if it favors the adoption of the cleaner technology.

Even though this model is capable of showing why the Porter hypothesis might be true and explain how a properly designed policy can allow firms over time to become more efficient and ultimately become more productive, there is an issue which he looks at in more detail. In the model proposed, in fact, after the policy implementation it is optimal to increase waste production because the technological improvement means that firms can produce more output per unit of waste, so that the opportunity cost of abatement increases. The proposal of the theme of the possibility of pollution increasing due to new technologies being introduced is therefore to be looked at with care. The policy choice, we understand, is fundamental in ensuring both economic soundness and environmental friendliness: the regulation must, in fact, be so that at the same time it is capable of making the cleaner and newer technology adopted, so that productivity increases can be reaped, but we must also ensure the environmental feasibility of it, for example by setting maximum amounts of pollution emittable, with such instruments as cap-and-trade systems.

2.4 Environmental regulation and the age of the capital stock

An argument which has helped framing more clearly the problem of the relationship between stricter environmental rules and increased competitiveness has been presented by Xapapadeas and de Zeeuw (1998), who construct a model that has the credit for making the trade-off between environmental regulation and industrial profitability less sharp, although not supporting the existence of a 'win-win' situation as posited by the Porter hypothesis.

The authors consider an economy in which firms can invest in capital with different ages. The age of the machine will be determining production, running costs and emissions: newer machines, in fact, will be more productive as they embody better technology; will have lower running costs; and will emit an equal or smaller amount of pollution than older machines. We also assume that the firms need to pay an environmental tax. The authors now define an infinite time horizon optimal control problem with transition dynamics described by a linear partial differential equation which will represent the firm's choice to buy or sell the machines of different ages in order to maximize their profits. Therefore, we will have that in each period we will define an optimal age distribution which, of course, will depend on the costs, and among them, the environmental tax. The authors are able to show that an increase in the emission tax has, as a result, a reduction in the number of machines in the capital stock of each firm for every age, implying that the age distribution of the machines is shifted downward from the preceding optimal age distribution. This effect they call the 'downsizing' effect: the capital stock of the firms in the economy is reduced.

Now the authors turn to the central question of whether an increase in the emission tax increases the average productivity of the capital stock: they find that this is the case only under certain circumstances. For the productivity to increase we must have a decrease in the average age of the capital stock, as newer machines are more productive, and this happens if and only if the average age of the optimal capital stock before the tax increase is less than the average age of the change in the capital stock, due to the downsizing effect caused by the tax rate increase. Therefore, under the stated conditions, we have that the increase in the environmental taxes renews the capital stock and therefore reduces the optimal average age: this implies that stricter environmental policy increases the productivity of the capital stock because the average age of the capital stock is reduced. We have, therefore, that when the downsizing effect comes with the modernization effect the average productivity of the capital stock is increased, although this is not exclusive to stricter environmental policy but more generally to an increase in costs, so that the positive effect may effectively be caused by some other external shocks.

Stricter environmental regulation, however, is not seen as a 'free lunch' in the model because of the fact that the profitability of the firms is always decreased as a consequence of the implementation of the more stringent policy: this is the reason why the authors conclude that even though the Porter hypothesis may indeed be true, such a regulation can be non-optimal, so that eventually firms' profitability is always reduced, even though the effects of such a reduction are mitigated in the presence of the 'modernizing' effect. In fact, the additional costs of more stringent regulation are, in this model, alleviated by three effects: the 'downsizing' effect, which leads to an upward pressure on prices, the 'modernizing' effect, which increases capital stock productivity, and the joint effect of both, which allow to reach an emission target with a lower tax level.

We can understand, therefore, that though not justifying the belief in a 'free-lunch' available thanks to environmental regulation, the model is capable of re-framing the debate in a milder tone, laying the foundations for a more thorough research as to what the relationship between environmental policy and a more productive capital stock is.

2.5 Conclusions

These models, in conclusion, have the merit of showing the theoretical feasibility of the Porter hypothesis without the need to call for too extreme assumptions. The reason why very different results are arrived at in the literature is likely to be due, mostly, to differences in the properties which are attributed both to the innovation process and to the features of the policy. Regarding this last point, it is nowadays established that not all environmental regulations lead to the results of the Porter hypothesis, but rather it is market-based instruments- which make firms internalize the cost of the pollution externality they produce- that are capable of driving innovation; on the other hand, command-and-control regulations, those most popular in the second half of the XX century and therefore considered in the early analysis of the nexus between competitiveness and regulation, are less efficient in doing so and do not provide firms with the right incentives to innovate.

3 Empirical model

3.1 Modeling

We want to analyze the relationship between the stringency of environmental regulation and labor productivity using industry-level data over time. Our contribution would be to use the Emissions Trading System, implemented by the European Union, as a proxy of environmental regulation. The rationale for such a choice is that the EU ETS meets the economic efficiency and soundness requirements which we have highlighted in the previous section[4]: this is because they allow firms to internalize their cost of polluting and hence provide them with market-based incentives to comply with the regulation while retaining and even increasing their competitiveness and productivity. The EU ETS has been defined as 'arguably the most important market-based application of economic principles in the climate domain and the largest cap-and-trade program yet implemented' (Ellerman et al., 2014) and this justifies its use to empirically test the Porter hypothesis. We will therefore focus specifically on this instrument and we will estimate the following crude and reduced-form equation, using a fixed effects model:

$$\log productivity_{cit} = \beta_0 + \beta_1 ETS_{2005,cit} + \alpha_{it} + \mu_{ci} + \epsilon_{cit} \quad (1)$$

where i denotes industries, c countries, t years, *productivity* the gross value added by hour worked, and ETS_{2005} a dummy variable equal to 1 for the years, countries and industries where the EU ETS was in place after its first implementation, that is in 2005. Equation (1) posits that the EU ETS implementation in 2005 should have a contemporaneous effect on productivity. We will experiment with different lag structures. We have written the error term as composed of two interacted fixed components and a residual error term; the first interacted term captures the joint

[4]Cf. in particular, sections 2.1 and 2.3: the models by both Ambec and Barla (2002) and Mohr (2002) stress how it is fundamental for the implemented regulation to be market based, hence meeting the aforementioned requirements.

effect of industry and time fixed effects while the second country and industry fixed effects.

We need to note, however, that the 2005 implementation was just the first one of a still-evolving system[5] and we are lead to believe that the further modifications of the program may result in the effects supported by the Porter hypothesis. We will therefore test two more equations:

$$\log productivity_{cit} = \beta_0 + \beta_1 ETS_{2005,cit} + \beta_2 ETS_{2008,cit} + \alpha_{it} + \mu_{ci} + \epsilon_{cit} \tag{2}$$

$$\log productivity_{cit} = \beta_0 + \beta_1 ETS_{2005,cit} + \beta_2 ETS_{2008,cit} + \beta_3 ETS_{2013,cit} + \alpha_{it} + \mu_{ci} + \epsilon_{cit} \tag{3}$$

where ETS_{2008} and ETS_{2013} indicate dummy variables which allow us to capture the effect of both the second and third modifications of the EU ETS, which took place in 2008 and 2013 respectively. The choice is motivated by our desire to capture the additional effect of the subsequent changes to the regulation, which made it more stringent.

This means that for the years 2005-2007, Phase I of the project, the effect can be simply captured by the estimator $\hat{\beta}_1$ which will measure the impact of the beginning of this first phase, which was characterized by a desire to set a price for carbon and to put in place an adequate infrastructure for the monitoring, reporting and verification of emissions. For Phase II (2008-2012), where auctions had an increasing weight in the allocation of permits and a lower cap on allowances was set, the effect is captured by the estimator $\hat{\beta}_2$, but in equation (2) we include ETS_{2005} so as to consider the fact that the population had been previously treated. The same reasoning can be applied to Phase III (2013-2020): we need to include the dummy variables signaling the two previous tranches of the regulation because the population was not untreated at the time, and in order to capture the marginal effect of the 2013 policy reinforcement we need to incorporate them in our equation.

[5]The system is now moving into Phase IV, which begun in 2021 and is expected to end in 2030.

3.2 Data

The data on labor productivity is taken as the gross value added per hour worked in volumes by Stehrer et al. (2019) for the period 1995-2017. They are indexed using 2010 as the base year, meaning that the values are all equal to 100 in that year. We will use the two digit SIC classification for the manufacturing sector in order to properly take into account the implementation of the EU ETS which, as per the regulation, affects the following sectors[6]: wood and paper products, and printing; coke and refined petroleum products; chemicals and pharmaceutical products; rubber and plastic products, and other non-metallic mineral products; and basic metals and fabricated metal products, except machinery and equipment. All other sectors are considered at the 1 digit level. We will also consider the electricity, gas, steam and air conditioning supply sector as affected by the regulation, since the power sector has been included in the EU ETS since its beginning in 2005[7]. The ETS dummy variables therefore will be equal to 1 for the regulated sectors only- provided that the country and time dimensions also imply that the EU ETS was in place. Data is available for all EU countries as of January 1^{st}, 2020 with the addition of Japan, the United Kingdom and the United States. However we will not consider Bulgaria, Croatia, Romania or the United Kingdom for any period, given that the latter introduced an emissions trading system in 2002, anticipating by three years the common EU ETS framework, while the first three countries joined the European Union as the program had already been implemented. On the other hand, we include both Japan and the United States and consider them as an untreated group for the entirety of the 1995-2017 period[8].

[6] Cf. Annex I of the 2003 Directive (Official Journal of the European Union, 2003) and the 2011 Commission Decision (Official Journal of the European Union, 2011)

[7] See *supra* note 6.

[8] This choice is dictated by the complete absence of nationally implemented emissions trading systems in both Japan and the United States. We need to note here, however, that some local experiments were working in both countries e.g. the Saitama Prefecture Global Warming Strategy Promotion Ordinance in place in the Saitama Prefecture.

Table 1 summarizes the sectors that have been considered as impacted by the EU ETS regulations:

Table 1: Sectors considered affected by the EU ETS Regulation.

Sector Code	**Sector Description**	**Subject to EU ETS**
A	Agriculture, forestry and fishing	No
B	Mining and quarrying	No
C10-C12	Food products, beverages and tobacco	No
C13-C15	Textiles, wearing apparel, leather and related products	No
C16-C18	Wood and paper products; printing and reproduction of recorded media	Yes
C19	Coke and refined petroleum products	Yes
C20	Chemicals and chemical products	Yes
C21	Basic pharmaceutical products and pharmaceutical preparations	No
C22-C23	Rubber and plastics products, and other non-metallic mineral products	Yes
C24-C25	Basic metals and fabricated metal products, except machinery and equipment	Yes
C26	Computer, electronic and optical products	No
C27	Electrical equipment	No
C28	Machinery and equipment n.e.c.	No
C29-C30	Transport equipment	No
C31-C33	Other manufacturing; repair and installation of machinery and equipment	No
D	Electricity, gas, steam and air conditioning supply	Yes

E	Water supply; sewerage; waste management and remediation activities	No
F	Construction	No
G	Wholesale and retail trade; repair of motor vehicles and motorcycles	No
H	Transport and storage	No
I	Accommodation and food service activities	No
J	Information and communication	No
K	Financial and insurance activities	No
L	Real estate activities	No
M-N	Professional, scientific, technical, administrative and support service activities	No
O-Q	Public administration, defence, education, human health, and social work activities	No
R-S	Arts, entertainment, recreation; other services and service activities, etc.	No
T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	No
U	Activities of extraterritorial organizations and bodies	No

4 Empirical results

4.1 Results: industry analysis

Using the described data, our analysis seeks to estimate the effect of the implementation of the EU ETS- a market-based instrument aimed at lowering CO_2 emissions by putting a price on pollution- on labor productivity, measured as gross value added per hour worked. Table 2 presents our main results using interacted fixed effects and drawing upon the annual data sample.

Model 1- estimating equation (1)- allows us to test the effect of the first implementation of the EU ETS on labor productivity and, in line with the previous literature, we are able to show how a tightening in the stringency of environmental policy as captured by the introduction of a carbon market has a significant and positive short-term effect on industry-level productivity. In model 2 we extend equation (1) adding two time lags and hence admit the 2005 introduction of the Emissions Trading System to display its effects in subsequent years. The results suggest a significant positive effect in the same year the regulation is implemented which, however, turns negative in a two year lag. In the other models, we can see a similar pattern: in models 3 and 4 -estimating equations (2) and (3) respectively- we take into consideration the subsequent implementations by adding the dummies for the 2008 and 2013 modifications. For 2008 the effect is consistently and significantly negative, whereas for 2013 we have a contemporaneous positive impact, but it is insignificant at any conventional confidence level. Finally, model 5 allows the three implementations to show their effects also on the year following their initial setting out and, as per before, the results show a significant positive impact of the 2005 implementation, a negative significant impact of the 2008 modification and finally an insignificant contemporaneous effect of the 2013 change to the regulation which however turns to be significant and positive if we look at the one-year lagged effect.

Table 2: Dependent Variable: Labor Productivity

Variable	Lags	Model 1	Model 2	Model 3	Model 4	Model 5
ETS_{2005}	0	0.042***	0.043**	0.065***	0.065***	0.049***
		(0.013)	(0.017)	(0.014)	(0.014)	(0.017)
ETS_{2005}	1		0.031			0.024
			(0.024)			(0.020)
ETS_{2005}	2		-0.041**			
			(0.021)			
ETS_{2008}	0			-0.030**	-0.042***	-0.051**
				(0.013)	(0.015)	(0.022)
ETS_{2008}	1					0.001
						(0.022)
ETS_{2013}	0				0.024	-0.034
					(0.017)	(0.027)
ETS_{2013}	1					0.072**
						(0.030)
cons		4.285***	4.317***	4.285***	4.285***	4.285***
		(0.052)	(0.051)	(0.052)	(0.052)	(0.052)
Fixed effects						
Country*Industry		Yes	Yes	Yes	Yes	Yes
Country*Year		Yes	Yes	Yes	Yes	Yes
N		13,551	13,021	13,551	13,551	13,551
R^2		0.630	0.617	0.630	0.630	0.631

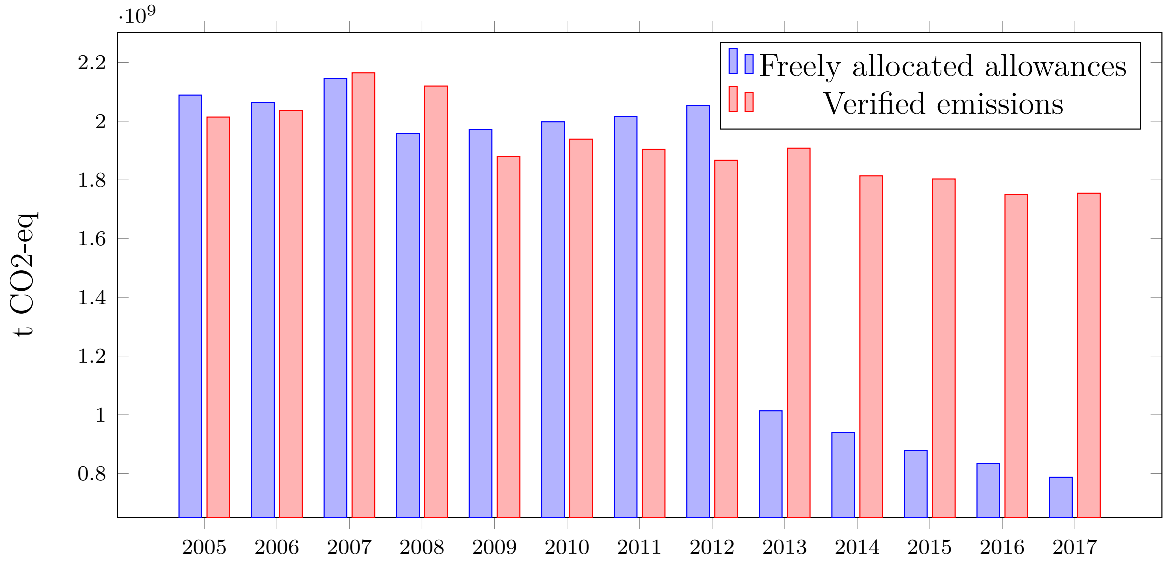
* $p < 0.1$;

** $p < 0.5$;

*** $p < 0.01$.

Robust standard errors in parentheses.

Fig. 1: Free allowances and emissions for all stationary installations



In order to properly explain our results, it will be convenient to take into consideration the relationship between the negative (or positive) impact of the regulation on any given year and the proportion of total allocated allowances to verified emissions. Figure 1 plots the number of verified emissions and freely allocated allowances[9] in the period 2005-2017 for all stationary installations included in the program. As we can see, the years 2005-2006 were characterized by an abundance of allowances: at that time generous caps and unexpectedly low abatement costs meant that firms initially experienced what Abrell et al. (2011) call the 'good years' of the program: this is also reflected by a fall in the price of allowances which went from initial values of more than €20 per EU Allowance Unit of tonne of CO_2 to €1 when market actors became aware that more allowances than needed

[9]Freely allocated allowances consisted of 100% of total allocated allowances in 2005 and no less than 98% of total allocated allowances for the entirety of Phase I of the program. Moreover, the share of allowances given out for free averaged 96.1% of total allowances in Phase II. The situation dramatically changes in Phase III in which freely allocated allowances and auctioned allowances made up similar share of total allowances.

were indeed available. With the evolution of the program, and especially with the beginning of Phase II, this situation changes: allowances become scarce and this is also reflected in their prices sharply rising to levels consistently higher than €20 per EUA. These facts are important for a proper explanation of our previous empirical results: as cheap available innovation and a generous allowance system were dominating the functioning of the EU ETS, highly-productive firms had the chance to reap the new opportunities offered by a carbon market in the form of new pollution abatement technologies while poor-performing firms still had the chance to cheaply buy the allowances in excess in the market. On the other hand, with the tightening of the regulation in the years 2007-2008, allowances became hard to come by and firms had to face tougher market conditions: this sharp change in the market environment and the forced effort of firms to cut back on emissions is reflected in the negative coefficients of the effect of the EU ETS regulation on labor productivity in 2007 and 2008. As firms, however, developed throughout time the technology to be able to cope with the increased tougher requirements imposed by the regulation, the negative constraint imposed easened and firms eventually experienced an increase in their productivity of labor. This latter result of increased long-term labor productivity thanks to the implementation of the EU ETS holds true, as per our empirical analysis, in the year subsequent to the 2013 modification- the one which made the regulation more similar to a market-based instrument, with a majority of allowances being given out through auctions rather than for free.

4.2 Robustness checks and endogeneity concerns

A robustness check was performed for the analysis: the specification tests the robustness of our results to the inclusion of the United States and Japan as untreated group for the period. The re-estimated results, reported in the appendix, are not significantly affected by the change in the countries included in the analysis, implying that our results do not hinge on the pool of countries considered for control. Potential endogeneity of the instrument used as a proxy for environmental regulation due to reverse causality or simultaneity may question our identification strategy. This could lead to problems in case good performance in given industries in terms of higher labor productivity makes adoption of more stringent measures easier or if firms that are performing poorly are able to lobby against more stringent measures. However, the EU ETS used as a proxy of stringency of environmental regulation makes it less likely that specific industries and firms were able to directly influence the regulatory process given that it happened at the EU and supranational level. Moreover, as we consider lagged values of the dummy, we could be reducing the simultaneity issues. Finally, our results are robust to the different specification tests.

5 Conclusion

In the last sixteen years, the Emissions Trading System implemented by the EU has meant lower emissions in the whole Union. The policy aims at achieving both climate neutrality by 2050 and, in the medium term, a 55% net reduction in greenhouse gas emissions by 2030. This instrument has obviously had economic effects in terms of reallocation of resources, investments made in capital and changes in the production processes of the firms and plants that have been affected by the regulation. The EU ETS is also expected to become ever more stringent in the future and to be accompanied by other climate policies and by increased investments in the green economy both in the European Union and abroad. These actions are all expected not only to improve, as intended, the environmental outcomes but they will also inevitably affect the purely economic outcomes where they are implemented. According to the Porter hypothesis, this shift towards a green economy, achieved through tight and market-based environmental policies, should result in a double dividend, given by both better environmental and economic performance.

We have therefore tested what has been the effect of the instrument developed by European institutions on productivity in a panel of EU countries along with Japan and the United States in the period 2005-2017. We find that more stringent environmental policy taking the form of a carbon market is associated with an increase in productivity if it is accompanied by a generous system of allowances being given to installations. However, a decrease in the number of allowances granted to firms is associated with a short-run decrease in the productivity of firms, which however turns positive in the longer term. This may be determined by firms being capable of having the time to adapt to the new conditions created and to achieve lower emissions along with increases in productivity. The market-based approach adopted in the European Union is theoretically capable of giving this empirical results by making firms internalize their cost of pollution, hence giving them incentives to develop and adopt newer technologies with a flexibility which is not permitted under a standard or command-and-control approach.

Our results tend to favor Porter's claim that, especially in the longer term, well designed environmental policies result in increased labor productivity. The Porter hypothesis suggests that stricter environmental regulation encourages research and adoption of new technologies which, in the end, contribute both to environmental benefits and enhancements in productivity. Hence, the policy implication is that environmental regulation should be designed so that it eventually leads to a socially-optimal quantity of R&D effort- which would not be undertaken absent the regulation- in order to achieve cleaner production technologies.

Appendix

Table 3: Dependent Variable: Labor Productivity

Variable	Lags	Model 1	Model 2	Model 3	Model 4	Model 5
ETS_{2005}	0	0.040***	0.041**	0.063***	0.063***	0.047***
		(0.013)	(0.017)	(0.014)	(0.014)	(0.017)
ETS_{2005}	1		0.030			0.024
			(0.023)			(0.020)
ETS_{2005}	2		-0.041**			
			(0.020)			
ETS_{2008}	0			-0.030**	-0.041***	-0.050**
				(0.013)	(0.015)	(0.022)
ETS_{2008}	1					0.001
						(0.022)
ETS_{2013}	0				0.023	-0.036
					(0.018)	(0.028)
ETS_{2013}	1					0.074**
						(0.030)
cons		4.263***	4.317***	4.263***	4.263***	4.264***
		(0.052)	(0.051)	(0.052)	(0.052)	(0.052)
Fixed effects						
Country*Industry		Yes	Yes	Yes	Yes	Yes
Country*Year		Yes	Yes	Yes	Yes	Yes
N		12,489	11,985	12,489	12,489	12,489
R^2		0.640	0.626	0.640	0.640	0.641

* $p < 0.1$;
** $p < 0.5$;
*** $p < 0.01$.
Robust standard errors in parentheses.

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