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The Effect of Energy Efficiency Enhancement on Innovation and Competitiveness.

Studie im Auftrag des Energie Trialog Schweiz und des Bundesamtes für Energie

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1 Introduction

Whereas much of the media debate about policies to save energy and reduce CO2 emissions has been cast in terms of a trade-off between environmental and economic efficiency, in the mid-nineties Michael Porter and Claas van der Linde suggested that this debate was incorrectly framed (Porter and van der Linde 1995). Their conjecture was, in essence, that stricter environmental regulations could facilitate a transition from "extensive" growth (growth fuelled by using more factors of production) to "intensive" growth (growth fuelled by more efficient use of factors), and was backed by Porter's vast "clinical" and case-study experience. Indeed, cursory evidence shown in Mathys (2007, figures 1 and 2) suggests that the second oil price shock of 1979, although temporary, triggered permanent gains in energy efficiency. Hysteresis in energy efficiency, in turn, suggests that induced innovation generates permanent changes in production processes. If price shocks trigger innovation, regulatory changes can have qualitatively similar effects, at least when they take place in sufficiently large and developed markets. Porter and van der Linde's pioneering conjecture is now known as the "Porter hypothesis" and has been widely discussed in academic and policy circles. In a nutshell, it is a "win-win" argument according to which tightening environmental regulations induces innovation, which in turn improves both environmental and economic efficiency.

However, the Porter Hypothesis is controversial. First, it has no theoretical backing, being a conjecture borne of casual observation. Second and perhaps more importantly, its empirical validity has been widely debated (see Cadot, Gonseth and Thalmann 2009 for a survey of the arguments). This debate matters not just academically: It is also highly relevant for the formulation of environmental policy. If more stringent environmental or energy standards reduce the ability of domestic firms to compete with foreign ones, the international regulatory environment is likely to be a race to the bottom in which every country tries to undercut others by loose environmental standards. Loose environmental standards are, in this context, a sort of hidden industrial policy, and only binding international treaties can provide the commitment mechanism needed to stop the race to the bottom. If, by contrast, stringent environmental standards promote profitable innovation, as per the Porter Hypothesis, policymakers can shift attention from "environmental diplomacy" to the design of unilateral policies at home. Moreover, environmental policy will spread by contagion, and first movers are likely to set the tone for others, capturing the environmental-policy agenda in a way that can be beneficial to home firms.

This report contributes to the debate with a novel empirical approach focusing on the capacity of industries to adapt to cost-raising environmental regulations. Our identification strategy proceeds as follows. In a first step, we construct an index of total factor productivity (TFP) that reflects the efficiency with which productive inputs are used. This index is calculated for a three-dimensional panel of 36 manufacturing industries tracked between 1985 and 2006 in 27 countries. In a second step, we use the economic equivalence between cost-raising emissions regulations and energy-price shocks to estimate their (common) effect on TFP. To do this, we regress TFP on energy prices and a set of control variables at the industry level. Our use of panel-data techniques allows us to control for unobserved heterogeneity between industries and countries. Thus, many parasite influences are filtered out of our analysis. In addition, we use a variable-coefficients approach interacting our key slope coefficients with industry-level dummy variables. This allows the effect of price shocks on TFP to vary across industries.

Beyond the use of panel data at the industry level, the primary originality of our approach comes from our postulate that industries with higher R&D expenditure or more skilled labor forces are better able to cope with energy-price shocks (and thus with environmental-regulation shocks) than others. If our postulate is true, two effects will work at cross-purposes. First, an energy-price rise will directly reduce TFP if it forces industries to invest in new, more expensive (but energy-saving) capital equipment to produce the same amount of output as before (and if energy savings are passed on to consumers). But it will also generate unexpected efficiency gains in industries that can harness brainpower to adapt their production processes. In order to identify this effect, we interact our two adaptive-capacity measures (R&D and worker skills, which we proxy in turn by worker compensation) with the energy-price variable. The indirect (TFP-enhancing) effect will show up in the regression as a positive coefficient on this interaction term. If this effect were to swamp the negative direct effect for some industries, this would provide very strong evidence in favor of the Porter Hypothesis, at least in the "adaptive-capacity" formulation adopted here.

The cost of our approach is that the combination of TFP and R&D data substantially reduces the sample's size (to 6 countries). In spite of this, we find very robust support for the Porter Hypothesis, with a positive net effect (direct plus indirect) in 70% of the industries. Because of their higher level of innovative activity, industries like chemical products, transport equipment, or radio, television and communication equipment have the strongest (positive) indirect effects and stand out as winners on net. As it turns out, we also find a very strong net positive impact of energy price shocks on productivity in the "coke, refined petroleum products and nuclear fuel" and "other non-metallic mineral products" industries, two sectors particularly exposed to energy prices due to their high energy intensity, possibly because they are characterized by low-hanging fruits in terms of improvements in both production processes and environmental performance. Results are stronger when using R&D as the measure of adaptive capacity than when using labor skills, possibly because the fixed-effects panel estimator uses only the within-industry (time) variation of the data, whereas the skill composition of industries varies little over time.

The report is structured as follows. Section 2 introduces the Porter hypothesis and reviews existing empirical results. Section 3 describes our methodology and estimating equation. Section 4 describes the data, and section 5 presents stylized facts on energy prices highlighting the source of the variation in the data. Section 6 presents our results and simulates the impact of higher energy prices on Swiss industrial productivity (for which direct results are not available for want of industry-level data). Finally, section 7 sums up our findings and discusses policy implications.

2 The « Porter hypothesis »

2.1 The hypothesis and its debate

In a celebrated article (Porter and van der Linde 1995), Porter and van der Linde suggested that "*properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs of complying with them*". Though their statement was based on a set of case studies, they expected, for several reasons, these innovation offsets to be widespread in the economy. First, they argued that firms are not profit maximisers, in which case environmental regulations can stimulate profitable innovation simply by putting firms under a new pressure. In particular, such additional pressure contributes to "*overcome organizational inertia, foster creative thinking and mitigate agency problems*". Second, Porter and van der Linde interpreted emissions and discharges as being a sign of resource inefficiency which further "*force firm to perform non-value-creating activities such as handling, storage and disposal*". More generally, they underlined the fact that "*efforts to reduce pollution and maximize profits share the same basic principles, including the efficient use of inputs, substitution of less expensive materials and the minimization of unneeded activities*". Third, regulation provides or generates information (i.e. a public good that may be underprovided in the absence of regulation) thereby potentially allowing firms to benefit from previously unknown profit opportunities. Fourth, environmental regulation may encourage firms to carry out (on average) profitable but risky investments that also deliver environmental benefits. Finally, they stated that domestic environmental regulations could provide an early-mover advantage allowing firms to gain international market share. With respect to international competition, they also emphasized the fact that internationally competitive industries seemed to be much better able to adapt to environmental regulation through innovation than industries that were uncompetitive to begin with.

The conjecture that environmental regulations can enhance competitiveness, known today as the Porter Hypothesis, has been the object of an extensive exegesis, with later authors (starting with Jaffe and Palmer 1997) distinguishing between Porter's "weak", "narrow" and "strong" hypotheses. All essentially say that properly designed environmental standards can encourage innovation. The conjecture has also been the object of many criticisms [Palmer et al. (1995), Oates et al. (1993)]. Not only the sceptics have criticized each of the arguments given above and have brought into question the representativeness of the case studies provided by Porter and van der Linde, but they have also emphasized the opportunity cost associated to the development or the adoption of a new environmentally friendly technology. In fact, even in case innovation offsets outweigh the costs of compliance, resources used to comply with environmental regulations might well have been used to finance more profitable investments.

The debate surrounding the Porter hypothesis is not yet resolved. The following table, taken from Jaffe et al. (2000), conveniently summarises the areas of agreement and disagreement among economists regarding the link between environmental regulation, innovation and competitiveness:

AREAS OF AGREEMENT	
Historical evidence indicates that a significant but not predominant fraction of innovation in the energy and environment area is induced.	
Environmental regulation is likely to stimulate innovation and technology adoption that will facilitate environmental compliance.	
Much existing environmental regulation uses inflexible mechanisms likely to stifle innovation; "incentive-based" mechanisms are likely to be more conducive to innovation.	
Firms are boundedly rational so that external constraints can sometimes stimulate innovation that will leave the firm better off.	
First-mover advantages may result from domestic regulation that correctly anticipates world-wide trends.	
AREAS OF DISAGREEMENT	
Win-Win Theory	**Neoclassical Economics**
Widespread case-study evidence indicates significant "innovation offsets" are common.	Case studies are highly selective. Firms believe regulation is costly.
Innovation in response to regulation is evidence of offsets that significantly reduce or eliminate the cost of regulation.	When cost-reducing innovation occurs, the opportunity cost of R&D and management effort makes a true "win-win" outcome unlikely.
Pollution is evidence of waste, suggesting why cost-reducing innovation in response to regulation might be the norm.	Costs are costs; even if firms are not at the frontier, side-effects of pollution reduction could just as easily be bad as good.
Existing productivity or cost studies do not capture innovation offsets.	Existing productivity and cost studies suggest that innovation offsets have been very small
There is much evidence of innovation offsets even though existing regulations are badly designed. This suggests that offsets from good regulation would be large.	Since there is agreement that bad regulations stifle innovation, the apparent beneficial effects of existing regulation only show that case studies can be very misleading.

Table 1 *: The first part of the table ("areas of agreement") presents a few arguments related to the link between environmental regulation, innovation and competitiveness that are not debated among economists. More controversial issues are addressed in the second part of the table ("areas of disagreement"). The table is taken from Jaffe et al (2000).*

Naturally, many empirical analyses have tried to shed light on one or the other of the controversial issues raised by the Porter hypothesis. The next subsection provides a quick review of this literature.

2.2 Empirical evidence

Since Porter and van der Linde's writings, a substantial literature has looked at the effect of environmental standards and energy prices (the two can be loosely taken as having potentially similar effects) on two variables of interest: innovation and productivity.

2.2.1 Testing the induced innovation hypothesis

Innovation has been measured in the literature essentially by R&D intensity and successful patent applications (or, for a few papers, by product introductions---see Mathys (2007) for a few examples). By and large, the literature supports the idea that innovation responds to energy prices and regulation. At least two papers used panel data of US manufacturing sectors which allow controlling for unobserved industry-specific characteristics influencing innovative activities such as technological opportunities and/or importance of technological characteristics to market demand [Jaffe and Palmer (1997), Brunnermeir and Cohen (2003)]. In this strand of empirical analyses, Jaffe and Palmer (1997) find a significant positive association between R&D and lagged pollution control expenditures (the latter being a measure of regulatory stringency) in the within-industry across-time dimension. Nonetheless, the magnitude of the positive effect is rather small (elasticity of 0.15) and empirical evidence also suggests that it significantly varies across manufacturing sectors. Furthermore, they find no statistically significant relationship between regulatory compliance costs and patenting activity. While Jaffe and Palmer (1997) focus on measures of overall innovative activity at the industry level, Brunnermeir and Cohen (2003) more specifically analyse the effects of pollution control expenditures on patenting of environmental technologies. Like Lanjouw and Mody (1996), they find a significant positive relationship between pollution control expenditures and environmental patents. Popp (2002) similarly found a positive effect of energy prices on energy related innovation, although Newell et al. (1999) found little effect of energy prices on product innovation.

2.2.2 Impact of environmental regulation on productivity

As for productivity, the recent literature is thinner but the Porter Hypothesis has received empirical support on that front as well [Berman and Bui (2001), Lanoie, Patry and Lajeunesse (2008)]. Lanoie, Patry and Lajeunesse (2008) analyse the association between changes in environmental regulatory stringency and total factor productivity growth using data from Quebec manufacturing sectors. Using a dynamic setting, they find a negative short-run impact of regulation on total factor productivity. However, the impact is reversed over a four-year period as their coefficients estimates lead to a positive long-run impact. In words, their results suggest that innovation induced by regulation more than fully offsets, in the long-run, the negative impact of regulation on TFP arising from investments in unproductive pollution control equipment. They also find some evidence that firms in manufacturing sectors that are more exposed to international competition tend to innovate more in response to tighter environmental standards. On the contrary, they do not find evidence that heavily polluting industries' productivity benefits more from environmental regulation than low polluting industries' productivity. Using plant-level rather than industry-level data, Berman and Bui (1998) found that California's oil refineries that had been subjected to stiff environmental regulations turned out to have higher productivity than comparable ones not subjected to the regulations.

In all, empirical analyses have not yet settled the issues related to the Porter hypothesis. Furthermore, some authors, following Porter and van der Linde (1995, p.109), have raised the issue that some results contained in the aforementioned empirical analysis could be biased against the Porter hypothesis, since approaches deterring innovation (i.e. command-and-control approaches) are predominant in environmental policy.

3 Scope of the project and methodology

From subsection 2.2, it should be visible that most of the attention has been devoted, in the last decade, to finding a causal relationship between energy prices or regulation on one hand and innovation on the other.[1] However, even when regression estimates were significant with a causal interpretation, studies of this type would not provide full testing of the Porter hypothesis: Showing that regulation triggers innovation is important in itself, but it is not enough to show that regulation can enhance competitiveness. In this respect, investigating the link between energy prices or regulation and *productivity* is closer to the spirit of the Porter hypothesis. Moreover, there are still possibilities to expand the existing literature on productivity in several directions.

Accordingly, our approach in this study is to use total factor productivity (TFP, see Box 2) as our performance indicator. TFP is what comes closest to matching the popular notion of "competitiveness" with a measurable concept of productive efficiency. Our unit of observation is at the industry × country level and over time. Our maintained hypothesis is that a shock on energy prices, be it caused by policy or market changes, forces firms to adapt their production processes in a way that may uncover unexpected efficiency gains. When this happens, the strong form of the Porter Hypothesis can be verified; that is, the shock generates not just environmental efficiency gains, but also, as a spillover, productive efficiency gains as well. Anecdotal evidence on regulatory experiments in Switzerland suggests that such induced efficiency gains are not a view of the mind. Following the introduction of the Volatile Organic Compounds (VOC) tax in 2000, the Swiss Federal Office for the Environment (FOEN) attempted to monitor how firms responded to their new regulatory environment. In addition to a 9'100 tons reduction in VOC emissions (subjected to the tax) between 1998 and 2001[2], the FOEN identified a number of innovation offsets such as higher-quality products, reductions in material purchasing costs and in material waste, healthier and safer workplace conditions, and reduced waste-disposal and pollution-control costs.[3] Building on a very recent study

[1] One reason for this is the fact that R&D expenditures and patent data have been made available during this period.

[2] Another figure indicates that the printing sector, which is one of the main VOC emitter, has reduced its emissions by approximately 60% during the period 1998-2008.

[3] Some examples are succinctly described (in German and French) at the following FOEN web address: http://www.bafu.admin.ch/voc/01262/index.html?lang=fr.

(Schoenenberger and Mack, 2009), Box 1 more carefully presents the link between the Swiss VOC tax and innovation.

Box 1: Environmental taxation and innovation: a Swiss case study

Starting on January 1st, 2000, the Swiss Confederation has been levying a tax on certain Volatile Organic Compounds (VOCs) with the aim of reducing the production of tropospheric ozone in Switzerland. The tax rate has risen from an initial CHF2.00/kg VOC to CHF3.00/kg VOC (annual tax revenues for 2006 and 2007 amount to CHF126.7 million). The tax is also applied to some imported products when they contain more than 3% of these substances, but exports are exempt; so, from an economic point of view, the tax acts as a consumption tax rather than as a production one. It is one of the very few market-based environmental policy instruments currently used in Switzerland. As the tax burden may be substantial for sectors like printing, paints/varnishes, or precision turned parts, it is a natural candidate for investigating whether firm-level innovation has reacted to its introduction.

Based on discussions with a set of about twenty firms in the three sectors mentioned above, Schoenenberger and Mack (2009) have highlighted induced product innovations and changes in production processes attributable to the VOC tax. In all interviewed firms, production processes have been optimized and adapted in order to reduce VOC emissions. Swiss producers of paints and varnishes have also launched new products that partially or fully eliminate VOCs from the production process. Thus, in the paints and varnishes sector, the case-study evidence is suggestive of a positive effect on product innovation. However, the authors provide no indication that early adoption of the regulation by the Confederation has put national producers of paints and varnishes at a competitive (first-mover) advantage compared to their E.U. competitors in the perspective of the Commission's adoption of Decopaint, a broadly similar regulation.

Not all firms and industries are equally capable of adapting to new conditions though. Following a strand of the literature going back to the pioneering work of Cohen and Levinthal (1989), we assume that R&D makes firms better able to absorb technology and thus to adapt to outside developments like unforeseen regulatory changes.[4] We also make the same kind of hypothesis with workers' skill (as measured at the industry level by labour compensation per employee relative to the manufacturing average), where we expect firms with more skilled workers of being more capable to adapt to new external constraints. Thus, our identification strategy consists of proxying the capacity to adapt by R&D expenditures and labour compensation. Econometrically, this means interacting industry-wide energy prices with industry-

[4] The results described in Jaffe and Palmer (1997) also give support to this idea, though indirectly. In fact, the data that they used provide some evidence that high-tech industries use fewer resources for pollution control than low-tech industries on average. Since they used pollution control expenditures as a measure of environmental regulation stringency, this trend seems apparently to indicate that high-tech industries are less regulated than low-tech industries. However, they emphasized the fact that pollution control expenditures can also measure how effective is an industry's response to regulation. In this light, the trend seems to indicate that high-tech industries have developed more effective response to regulation than low-tech industries.

specific R&D expenditures and labour compensation. Since there are differences in costs of scientists or research equipment across countries, we could also try to adopt interaction terms of the form "energy price × R&D expenditures × country dummy" in place of the more conventional interaction term "energy price × R&D expenditures". We expect energy-price rises to have a negative effect on TFP (if firms react to higher energy prices by purchasing new, more expensive capital equipment to produce the same amount of output), but the interaction terms "energy price × R&D expenditures" (or "energy price × R&D expenditures × country dummy") and "energy price × labour compensation" to have a positive and significant effect, mitigating or possibly reversing the direct effect.

Porter and van der Linde (1995) also suggested that internationally competitive industries have a greater ability (or greater incentives) to adapt to environmental regulation through innovation than industries sheltered from competition. Though formulated vaguely, this hypothesis can also be tested in our framework. Paralleling the approach described above, we interact the share of exports in production with energy prices. In this expanded model, the negative impact of industry-wide energy price rises is mitigated by the presumed higher adaptability of exporting firms.

Basically, the addition of interaction terms makes it possible to model different industries' responses to changing energy prices depending on some relevant industries' characteristics. In this report, we focus on industry-specific characteristics such as technological and managerial sophistication and exposition to international competition. Of course, it is possible to think of other industry-specific characteristics. For instance, a natural candidate would be energy intensity or pollution intensity if we were to analyse the impact of environmental regulation stringency on TFP.[5] Unfortunately, energy intensity data of manufacturing sectors are lacking at the level of industry aggregation that interests us. Accordingly, it was not possible to test for differentiated impacts of higher energy prices on TFP according to the sectors' energy intensity.

[5] In their paper, Lanoie, Patry and Lajeunesse (2008) explicitly tested whether the impact on TFP growth of environmental regulation is more beneficial for industries that are initially more polluting.

Box 2. Total Factor Productivity

Total factor productivity (TFP) can be thought of as the margin by which observed value added exceeds—or falls short of—the level predicted by a postulated production function. Assuming a Cobb-Douglas form in capital and labor, we have thus

$$TFP = \frac{Y}{L^{\alpha} K^{1-\alpha}} \quad (1)$$

where Y is measured value added, L is employment and K the stock of capital. In (1), the coefficient α is unknown. One approach consists of replacing it by the average value of the share of labor in value added. An alternative approach consists of retrieving it as the coefficient on labor in a log version of (1) estimated econometrically. Both methods have been used in the literature.

Set out in simple terms, an increase in TFP indicates that a firm, a sector or an economy is able to produce more value added from an unchanged level of production factors (labor, capital). TFP growth can be one of many reasons to explain why an economy expands. However, it has the particularity to be the source of growth most closely identified with technological gains. At the firm or sector level, an increase in TFP is also triggered by innovation. Firms with higher TFP are more competitive since an increase in TFP diminishes average costs of production.

Note that, in a competitive industry, a reduction in intermediate consumptions per unit of output will translate into a reduced output price thereby keeping *value added* (gross output minus intermediate consumptions) at a constant level. As a result, TFP will not be affected since it is the excess of *value added* over what is predicted by the Cobb-Douglas production function given observed quantities of capital and labor. A rise in TFP means that more value added is squeezed out of capital and labor, irrespective of the amount of intermediate consumptions. For instance, improvements in energy efficiency bear no particular relationship with changes in TFP. Thus, our application of the Porter-Hypothesis logic to TFP means that we are looking for improvements in the use of capital and/or labor as a by-product of adaptation to new environmental regulations, over and above any reduction in emissions or energy use.

The empirical analysis goes in two steps. In Step 1, we measure TFP at the industry level using the two alternative approaches described in Box 2. *Figure 1* presents a scatterplot of these two measures.

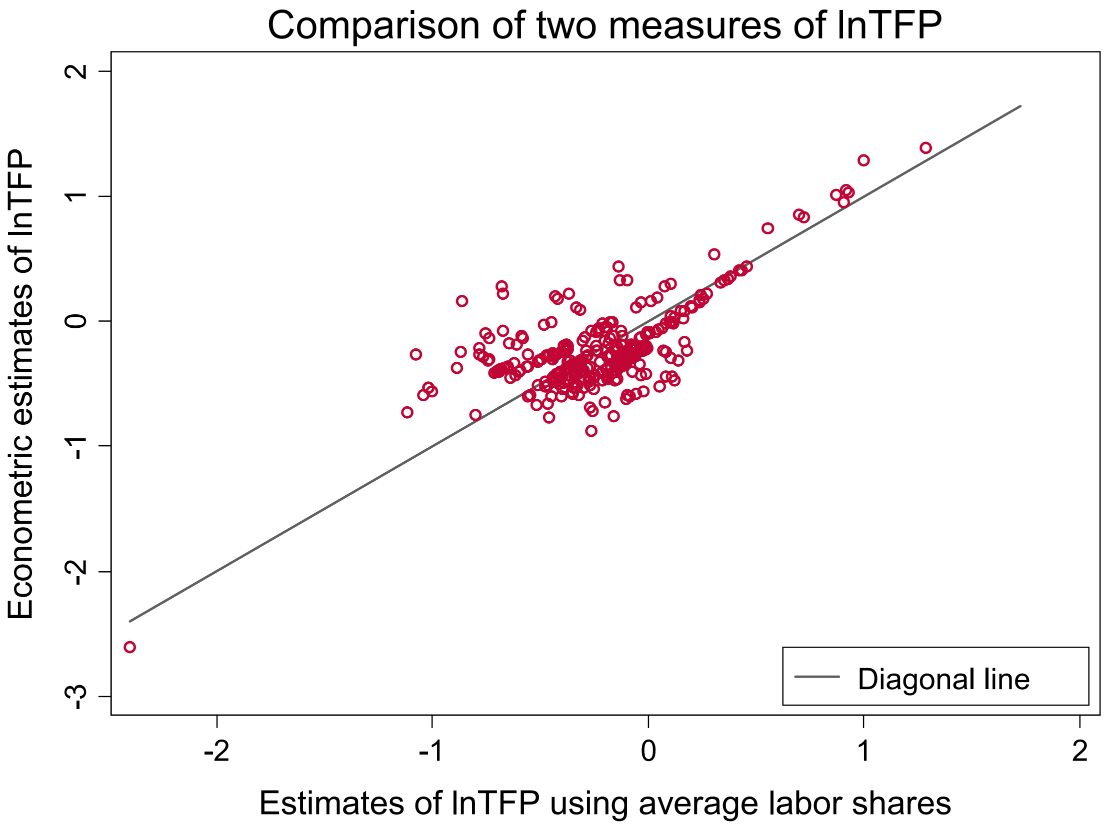

Figure 1 : *Plot of the econometric estimates of TFP against the estimates of TFP using average labor shares (each circle represents an industry × country pair).*

In Step 2, we regress TFP on treatment and control variables, using year dummies and, in the fixed effects model, country × industry fixed effects. The use of fixed effects makes it possible to control for time-invariant unobserved variables affecting the level of productivity at the industry level in a given country, regulations or other. In addition, year dummies allow controlling for a different sort of unobserved effects, that is to say those effects that are industry-invariant but that change over time (e.g. technological progress).

We use as control variables the share of exports in production, the rate of import penetration, the value of output, the number of establishments, exchange rates, R&D expenditures, and labour compensation per employee (relative to the manufacturing average). Openness to international trade and the number of establishments control for changes in industry pricing policies due to changes in the competitive environment, which could otherwise "pollute" the measurement of TFP. Exchange rates control again for changes in pricing policies for exported products due to appreciation or depreciation of the home currency. We expect the coefficient on the share of exports in production and exchange rates to be positive. On the contrary, we expect the coefficient on the rate of import penetration and the number of establishments to be negative. In particular, we will expect the coefficient on the number of establishments to be negative in case the variable is a relevant measure of market power at the industry level. Inclusion of the variable given the value of output allows capturing the effects of scale economies on productivity. Its related regression coefficient is expected to be positive. R&D expenditures and labour compensation are proxies for technological or managerial sophistication, which are, as explained above, key to our identification strategy.

Our treatment variable is the price of energy. More precisely, it is the net consumer price of energy faced by the industry, which can be disaggregated into two components: a price excluding taxes, and total taxes. The latter part of the net consumer price includes taxes levied by private bodies on a non-governmental basis when they exist (such as Switzerland's climate cent) but does not include the amount of the value-added tax. Our data contains a host of separate energy prices, but they are highly correlated, so which one is used in the analysis is largely inconsequential. Choosing one energy price as our treatment variable is theoretically appealing since the Porter hypothesis assumes "properly designed environmental standards". The qualifier "properly designed" applied to regulation means that the latter allows firms to find least-cost solutions for meeting environmental targets, including innovation. Actual regulation, mainly command and control, rarely has this property. Price regulation such as energy taxes does. Therefore, we analyse the response of firms and their TFP to changes in energy prices as a proxy for efficient price regulation.

As explained above, we interact energy prices with R&D intensity and labour compensation in order to verify if, in accordance with Porter and van der Linde's intuition, energy-price shocks, mediated by capacity-to-adapt proxies, can be shown to lead to overall productive efficiency gains. Moreover, we also interact energy prices with the share of exports in production in order to test whether industries' response to energy-price shocks depends on how heavily industries are exposed to international competition.

Formally, the baseline equation we run is

$$\begin{aligned}\ln(TFP_{ict}) = {} & \alpha_0 + \alpha_1 \ln(PRICE_{ct}) + \alpha_2 \ln(R\&D_{ict}) + \alpha_3 LABEMPM_{ict} + \alpha_4 XPROD_{ict} \\ & + \alpha_5 \ln(PRICE_{ct}) XPROD_{ict} + \alpha_6 \ln(PRICE_{ct}) LABEMPM_{ict} \\ & + \alpha_7 \ln(PRICE_{ct}) \ln(R\&D_{ict}) + \boldsymbol{\alpha}^{\mathbf{T}} \mathbf{x_{ict}} + \delta_{ic} + \delta_t + u_{ict}\end{aligned} \quad (2)$$

where i is an industry, c a country, and t time, $PRICE_{ct}$ is the price of energy in country c at time t (industry-invariant), $R\&D_{ict}$ is R&D spending, $LABEMPM_{ict}$ is labor compensation per employee relative to the manufacturing average, $XPROD_{ict}$ is the share of export in production, and $\mathbf{x_{ict}}$ is a vector of additional control variables including, as discussed, the value of output ($PROD_{ict}$), the rate of import penetration ($MPEN_{ict}$), the number of establishments ($ESTAB_{ict}$), and exchange rates ($EXRATE_{ct}$). The remaining components of the model are δ_{ic}, which is a country $\times$ industry fixed effect, δ_t, which is a time fixed effect, and the error term u_{ict}. Finally, note that the dependent variable is in logs. Among the set of independent variables, the price of energy, R&D spending, the value of output, the number of establishments and exchange rates are also in logs.

Partially derivating equation 2 with respect to the energy price variable gives a formula for computing the extent to which a rise in energy prices affect TFP at the industry level. Result from this derivation is shown in equation 3.

$$\frac{\partial \ln(TFP_{ict})}{\partial \ln(PRICE_{ct})} = \alpha_1 + \alpha_5 XPROD_{ict} + \alpha_6 LABEMPM_{ict} + \alpha_7 \ln(R\&D_{ict}) \quad (3)$$

More precisely, we will interpret this derivation as giving the partial elasticity of TFP with respect to energy prices (i.e. the approximate percentage change in TFP when energy prices increase by one percent). In the following, we will also often refer to it as the (net) partial effect of energy prices on TFP.

Equation 3 is no longer valid when the baseline equation is expanded so as to include terms interacting the energy price variable with industry-level dummy variables and triple interaction terms of the form "energy price × R&D expenditures × country dummy". For this expanded model, the partial effect of energy prices on TFP is given by the following equation.

$$\frac{\partial \ln(TFP_{ict})}{\partial \ln(PRICE_{ct})} = \alpha_1 + \gamma_i + \alpha_5 XPROD_{ict} + \alpha_6 LABEMPM_{ict} + \alpha_{7,c} \ln(R\,\&\,D_{ict}) \qquad (4)$$

where γ_i is the coefficient of the term "energy price × dummy for industry i". Compared to equation 3, note also that the coefficient multiplying the logarithm transformed values of R&D spending is now a country-specific coefficient. For the purpose of interpreting our econometrical results, it will be attractive to decompose the net partial effect described in equation 4 into two components $\alpha_1 + \gamma_i$ and $\alpha_5 XPROD_{ict} + \alpha_6 LABEMPM_{ict} + \alpha_{7,c} \ln(R\,\&\,D_{ic})$. The first component, which changes only according to the manufacturing sector *i*, gives the magnitude of the negative direct effect of higher energy prices on TFP. As to the second component, it gives the extent to which this detrimental direct effect is mitigated in each industry × country pair.

4 Data

International comparisons at the sector level are possible using currently available databases. We constructed a panel data set that nominally covers 23 manufacturing sectors in 27 countries (sectors classified at the 2 digit level of ISIC Rev.3) during the period 1985-2006, yielding a nominal sample size of about fourteen thousand observations. The availability of such large panel data sets at the industry level is only recent. However the need to measure productivity from a set of industrial data and to combine this industrial performance measurement with R&D data reduces sample size drastically, to 691. The need to control for an observed confounding variable (i.e. a variable whose effect on the dependent variable can be mixed up with the effect of other explanatory variables) further reduces sample size to 322. For instance, Swiss manufacturing sectors are not part of our sample due to missing data on labour costs, capital stock and R&D spending. The breakdown by country is as follows:

Belgium	19
Czeck republic	43
Denmark	38
Finland	117
France	48
Italy	57
Total	*322*

Table 2 *: Breakdown by country for our sample.*

Similarly, our sample's observations are not homogenously distributed across different manufacturing sectors. The breakdown by industrial sector is as follows:

Wood and products of wood and cork	42
Coke, refined petroleum products and nuclear fuel	43
Chemicals and chemical products	41
Rubber and plastics products	44
Other non-metallic mineral products	56
Basic metals	9
Fabricated metal products, except machinery and equipment	9
Office, accounting and computing machinery	9
Electrical machinery and apparatus, n.e.c.	9
Radio, television and communication equipment	9
Medical, precision and optical instruments	9
Motor vehicles, trailers and semi-trailers	21
Other transport equipment	21
Total	*322*

Table 3 *: Breakdown by manufacturing sector for our sample.*

Table 4 presents some of the variables contained in the data set along with the source of the data.

Extracted variables	Data source	Data provider
Total R&D expenditures	ANBERD database	OECD
Total price, price excluding taxes and total tax for the following products: *High Sulphur Fuel Oil; Low Sulphur Fuel Oil; Light Fuel Oil; Automotive Diesel; Premium Leaded Gasoline; Regular Leaded Gasoline; Premium Unleaded Gasoline (95 RON); Premium Unleaded Gasoline (98 RON); Regular Unleaded Gasoline; Natural Gas; Steam Coal; Coking Coal; Electricity*	Energy Prices and Taxes database	IEA
Number of establishments	INDSTAT4 2008 database	UNIDO
Production; Intermediate Inputs; Value Added at Basic Prices; Gross Fixed Capital Formation (all the previous variables both at current and constant prices); Labour Costs; Total Employment; Gross Capital Stock; Net Capital Stock	STAN database for industrial analysis	OECD
Contribution to Manufacturing Trade Balance; Export/Import Ratio; Export Share of Production; Import Penetration; R&D Intensity using Value Added; Labour Compensation per Employee relative to Total Manufacturing; Investments Shares relative to Total Manufacturing	STAN Indicators	OECD
Official exchange rate	World Development Indicators database	World Bank

Table 4 : *Enumeration of some of the variables extracted for the project. The names of both the original databases and the institutions providing the data are also given.*

Given the methodology discussed in the previous section, an obvious alternative to our industry estimation would have been to carry out the analysis at the firm level. However, international firm-level data sources do not provide the data needed to estimate production functions. For instance, the AMADEUS database, though including millions of European firms, among which 300'000 Swiss firms, provides comprehensive and usable financial data — obtained from the companies' annual report – only for a very limited number of firms. For that reason, our ability to analyse, at the firm level, the effects of environmentally or energy related national regulations, using models developed in the treatment effects framework, is limited.

5 Features of energy prices

Given our treatment variable, the Porter hypothesis can only occur in our sample if the pressure for innovation coming from energy prices is sufficient. We expect substantial innovation offsets to be more likely with stringent environmental regulation or large rise in the prices of raw materials. Before searching for any empirical evidence of the Porter hypothesis, it is therefore important to verify whether industries included in our sample have faced energy price changes susceptible to have triggered innovation. In order to do so, *Table 5* summarizes, based on information extracted from the Energy Prices and Taxes IEA database, light fuel oil price changes for different countries.[6]

[6] Light fuel oils are obtained at the early stages of petroleum distillation. They are used for heating and engines. Not that, for Switzerland, IEA likens light fuel oils to the French term of “Huile extra-légère (mazout)” and the German term of “Heizoel extra-leicht”. We have chosen light fuel oil price as our treatment variable only for data coverage reasons. As already mentioned, prices of the energy products included in the Energy Prices and Taxes IEA database are theoretically interchangeable in our analysis due to the fact that they are highly correlated.

Country	Time period	Percentage changes in the real price of light fuel oil: (Δp/p)*100			
		Annual percentage changes			Over the time period
		Min	Max	Median	
Austria	1985-1998; 2003-2006	*-21.1*	*19.5*	*-1.1*	*2.6*
Belgium	1995-2006	*-20.2*	*59.8*	*8.5*	*154.4*
Canada	1985-2004	*-23.2*	*66.9*	*-4.0*	*2.7*
Czech Rep.	1995-2006	*-20.4*	*35.8*	*1.6*	*47.3*
Denmark	1985-2006	*-33.8*	*37.2*	*3.8*	*42.2*
Finland	1985-2006	*-35.2*	*37.1*	*4.6*	*34.1*
France	1985-2006	*-22.4*	*42.1*	*3.4*	*0.1*
Germany	1991-2006	*-16.9*	*51.5*	*0.8*	*95.3*
Greece	1995-2005	*-17.5*	*41.6*	*2.9*	*45.3*
Italy	1985-2005	*-17.8*	*22.4*	*3.1*	*74.9*
Japan	1985-2006	*-28.8*	*30.4*	*0.4*	*2.9*
Korea	1998-2006	*-2.8*	*25.1*	*8.9*	*100.9*
Luxembourg	1995-2006	*-18.4*	*50.5*	*5.9*	*114.8*
Norway	1985-2006	*-29.7*	*21.8*	*2.4*	*68.8*
Spain	1985-2006	*-25.3*	*43.0*	*2.5*	*-2.1*
Sweden	1993-2005	*-13.7*	*47.3*	*5.7*	*87.5*
Switzerland	1990-2006	*-23.4*	*77.1*	*5.1*	*101.3*
United Kingdom	1985-2003	*-38.3*	*52.2*	*-1.9*	*-32.4*
United States	1987-2006	*-25.7*	*61.2*	*-2.5*	*112.1*

Table 5 : *min, max and median annual percentage changes in the real net consumer price of light fuel oil faced by the industry sector for 19 countries. The last column gives the percentage change in the real net consumer price of light fuel oil for the entire period covered by the data.*

Over the sample period, the real net consumer price of light fuel oil faced by industry increased in nearly all countries. The price (in real terms) has increased by more than 50% in nine countries and has even more than doubled in five countries. A notable exception is the United Kingdom where the price decreased by roughly 30% during the 1985-2003 period. It is also worth noting that, for 15 out of 19 countries, the median annual percentage change is positive which means that prices rose at least half the years in the sample period. By and large, many countries have seen energy prices significantly rising over the sample period. There is also substantial volatility, as indicated by the large values of maximum annual changes computed in several countries (e.g. +66.9 for Canada; +77.1% for Switzerland).

With this brief description of stylized facts in hand, we now turn to a discussion of the potential causes behind observed price shocks. In particular, are the large price increases observed in some countries caused by higher energy taxes or other factors? Several factors other than changes in energy taxation can explain national differences in the way light fuel oil price has changed over time. First, the *level* of taxation differs across countries, and a given change in international market prices will translate into a larger (relative) change in national energy prices in countries with low tax levels than in countries with higher levels. Therefore, differences in tax levels provide an explanation for the differences in annual percentage changes displayed in *Table 5*. Second, fluctuating exchange rates over time can also explain national differences in the evolution of light fuel oil price. For instance, the continuous US dollar depreciation against the British pound sterling (roughly -20% during the 1985-2003 period) has contributed to make light fuel oil cheaper for the British industries. As regards national evolutions of light fuel oil taxation, they can be thoroughly analysed for certain countries using again information extracted from the Energy Prices and Taxes IEA database.[7] The results are displayed in *Table 6*.

[7] Moreover, information taken from Infras (2007) on different national energy tax systems is also used in order to carry out this analysis.

Country	Time period	Initial measure of tax wedge (%)	Final measure of tax wedge (%)	Change in (real) total taxes over the time period (%)	Incentive taxes affecting light fuel oil price
Austria	1985-1998; 2003-2006	*14.0*	*22.2*	*63.1*	-
Belgium	1995-2006	*9.5*	*3.9*	*3.5*	-
Denmark	1993-2006	*7.8*	*4.9*	*29.6*	CO_2 tax (1992) SO_x tax (1996)
Finland	1985-2006	*8.1*	*13.4*	*122.8*	CO_2 tax (1990)
France	1985-2006	*25.6*	*11.2*	*-56.1*	-
Germany	1991-2006	*15.4*	*12.2*	*54.6*	Green tax reform (1999)
Greece	1995-2005	*57.5*	*22.5*	*-43.2*	-
Italy	1985-2005	*20.5*	*46.2*	*295.1*	CO_2 tax (1999)
Norway	1985-2006	*1.2*	*17.7*	*2367.0*	CO_2 tax (1991)
Spain	1985-2006	*4.4*	*16.0*	*251.6*	-
Sweden	1993-2005	*13.5*	*13.3*	*84.8*	CO_2 tax (1991)
Switzerland	1990-2006	*8.7*	*1.0*	*-76.0*	-
United Kingdom	1985-2003	*4.1*	*20.6*	*239.4*	-

Table 6 *: The table presents how light fuel oil taxation has evolved in 13 European countries. Our measure of tax wedge is equal to the ratio of real total taxes to real net consumer price where total taxes and real net consumer price include taxes levied by private bodies on a non-governmental basis but do not include the amount of the value-added tax. The last column displays, if any, incentive taxes affecting light fuel oil price [reported in Infras (2007)] that have become effective or that have been increased during the time period (the year in brackets gives the tax's year of introduction).*

Interestingly, *Table 6* shows very different evolutions of light fuel oil taxation across the 13 reviewed European countries. Light fuel oil taxation has increased in the Nordic countries (Denmark, Finland, Norway and Sweden) partly due to the introduction of CO_2 taxes in the early nineties. Light fuel oil taxation has also increased in Austria, Germany, Italy, Spain and in the United Kingdom. During the reviewed periods, these countries have taxed energy more heavily – for instance, through an increase in petroleum products taxation. While carried out for raising additional revenues in Austria, Spain and in the United Kingdom, this increased petroleum products taxation was environmentally motivated in Germany and Italy. Note also that higher light fuel oil taxation has only come with an increased tax wedge in Austria, Finland, Italy, Norway, Spain and the United Kingdom. As regards Belgium, light fuel oil taxation has remained nearly constant (in real terms). This status quo combined with higher prices on energy markets has led the tax wedge to decrease. At the end of 2006, no incentive taxes such as those primarily aimed at enhancing energy efficiency and/or reducing CO_2 emissions were effective in this country. Finally, light fuel oil taxation has significantly decreased in France, Greece and Switzerland thereby directly contributing to reduce the tax wedge. The French case deserves attention. Initially, taxes were an important part of the net consumer price of light fuel oil (i.e. 25.6% of the net consumer price in 1985). The tax decrease has reduced the tax wedge and, more importantly, has offset the effect of tighter market conditions on price as the real net consumer price of light fuel oil has been nearly unchanged in 2006 compared to 1985 (cf. *Table 5*). In other words, rising energy prices stemming from market changes has probably been neutralized by downward adjusted energy taxation. In this respect, the Greek case looks very similar to the French one. On the contrary, the case of Switzerland seems different since light fuel oil price (in real terms) has more than doubled between 1990 and 2006 as shown in *Table 5*. In fact, the decrease in light fuel oil taxation since 1990 has mainly occurred due to a decreasing need to levy contributions aimed at financing the creation of oil products' stocks. Note also that in Switzerland, from 01.01.2008 onwards, a CO_2 tax is levied on heating oil, natural gas and other fossil fuels used for heating purposes and process heat. According to IEA, the value of the tax is roughly equal to 0.032 CHF/litre for light fuel oil.

In conclusion, light fuel oil taxation has increased in the bulk of European countries during the reviewed periods. With the exception of Austria, higher level of light fuel oil taxation is partly attributable to the introduction and/or to the raising of incentive taxes. Higher level of taxation contributed to keep net consumer prices at a certain level or, as it is more often the case, to raise it. We can be a little bit more precise regarding the link between taxation levels and price levels since it can be evaluated while deriving the correlation coefficient between the level of total taxes and the net consumer price. We have computed this coefficient for the Euro-zone countries included in *Table 6*. Our result indicates that it is equal to 0.875 meaning that there exists a rather strong (positive) linear dependence between the distributions of total taxes and net consumer price.

6 Empirical results

6.1 Total factor productivity regression results

Coefficient estimates, robust t- and z-statistics are presented in *Table 7* for different panel data estimators. More precisely, results obtained with the pooled OLS estimator are given in the second and third column of *Table 7* (the model in the third column adds industry *and* country effects). Estimation results obtained with the fixed effects estimator are shown in the fourth column. All models include time dummies and interaction terms of the form "energy price × industry dummy". Moreover, the triple interaction terms "energy price × R&D expenditures × country dummy" are used in place of the interaction term “energy price $\times$ R&D expenditures” (cf. section 3 for explanations). Summary statistics of the different variables are displayed in Appendix 1.[8]

[8] Coefficient estimates obtained with the random effects estimator are not shown since they are identical to those displayed in the second column. With our model specification and data, the random effects estimator degenerates into the pooled OLS estimator. This particular feature sometimes happens with finite samples.

Variable	Pooled OLS	Pooled OLS	Fixed effects
XPROD	*0.017*	*0.034*	*0.001*
	(0.56)	*(1.28)*	*(0.03)*
MPEN	*0.002*	*-0.008*	*-0.015*
	(0.72)	*(-3.15)******	*(4.19)******
LABEMPM	*-0.011*	*-0.086*	*0.002*
	(-0.94)	*(-1.54)*	*(0.04)*
R&D	*-0.682*	*-0.801*	*-1.150*
	*(-1.86)**	*(-2.31)****	*(3.33)******
PROD	*0.129*	*-0.160*	*0.715*
	(1.13)	*(-0.94)*	*(6.23)******
PRICE	*-1.863*	*-4.091*	*-4.753*
	*(-1.72)**	*(-3.31)******	*(4.09)******
ESTAB	*-0.050*	*-0.070*	*-0.047*
	(-1.10)	*(-2.41)****	*(1.98)****
EXRATE	*-0.030*	*0.701*	*0.658*
	(-0.23)	*(1.56)*	*(1.88)**
Price*XPROD	*-0.003*	*-0.005*	*0.002*
	(-0.53)	*(-1.10)*	*(0.50)*
Price*LABEMPM	*0.002*	*0.015*	*-0.001*
	(1.11)	*(1.64)*	*(0.16)*
Price*R&D*dummy BE	*0.128*	*0.196*	*0.208*
	*(1.90)**	*(3.54)******	*(3.52)******
Price*R&D*dummy CZ	*0.132*	*0.175*	*0.258*
	*(1.86)**	*(3.02)******	*(4.06)******
Price*R&D*dummy DK	*0.131*	*0.163*	*0.214*
	*(1.90)**	*(2.95)******	*(3.51)******
Price*R&D*dummy FI	*0.130*	*0.182*	*0.214*
	*(1.92)**	*(3.22)******	*(3.64)******
Price*R&D*dummy FR	*0.129*	*0.123*	*0.199*
	*(1.93)**	*(2.11)****	*(3.56)******
Price*R&D*dummy IT	*0.124*	*0.137*	*0.186*
	*(1.86)**	*(2.39)****	*(3.39)******
Constant	*7.247*	*28.019*	*3.832*
	(1.49)	*(3.30)******	*(0.54)*
Price*Sector dummies	*Yes*	*Yes*	*Yes*
Sector dummies	*No*	*Yes*	*No*
Country dummies	*No*	*Yes*	*No*
Industry*Country pair dummies	*No*	*No*	*Yes*
Year dummies	*Yes*	*Yes*	*Yes*
R^2 adj.	*0.48*	*0.60*	*0.82*
Nbr of obs.	*322*	*322*	*322*

***Table 7**: This table presents the total factor productivity regression results using pooled OLS and fixed effects estimators. Robust t- and z-statistics are given in parenthesis (Cluster-robust standard errors are computed whenever the pooled OLS estimator is used). The meaning of the number of stars is as follows: * coefficient estimate significant at the 10% level; ** significant at the 5% level; *** significant at the 1% level. Country names are abbreviated in the following way: BE=Belgium, CZ=Czech Republic, DK=Denmark, FI=Finland, FR=France, IT=Italy.*

As shown in equation 2, our preferred model encompasses country × industry fixed effects. We do not a priori consider these unobserved effects to be uncorrelated with the explanatory variables used in the regression (i.e. our chosen setting is a fixed rather than a random effects model). In this framework, using the fixed effects estimator is desirable since it is always consistent. Consequently, we focus below on the estimation results obtained with the fixed effects estimator.

The sign of all the coefficients are consistent with our expectations. Focusing on energy prices, we find that their direct effect on industry TFP tends to be, as conjectured, negative. That is, after controlling for TFP heterogeneity across industries and countries, a rise in energy prices tends to reduce TFP, and, as it turns out, the effect is quantitatively large. On average, we find an elasticity of TFP to energy prices of about -4.75; that is, a 10% rise reduces TFP by a whopping 47.5%. This is in accordance with intuition if adaptation to higher energy prices takes the form of investment in technologically-advanced, energy-saving capital, which is likely to be more expensive per dollar of value added. It also suggests that, without adaptation of production processes, the impact effect of changes in energy prices, whether due to higher taxes or tighter world markets, is heavily penalizing.

We also find, quite naturally, that R&D expenditures (entered linearly in the equation) are positively correlated with TFP. What is most interesting for our purposes is that, after interacting energy price with R&D expenditures and country dummies, we find, for each country present in our sample, a positive indirect effect going against the direct one. The magnitude of this indirect effect then varies widely across industries and countries. On the other hand, the remaining interaction terms with energy price have not given rise to significant indirect effects. Apparently, R&D spending proves to be a better proxy for the capacity to adapt than labour compensation. However, this statement has to be somewhat qualified since the fixed effect estimator uses the time-series variation in the data while labour compensation mainly varies in the cross-section dimension (cf. Appendix 1). It is also worth noting that our results are obtained in a specification where interaction terms between energy price and industry-specific dummies have been added to the model (a variable-coefficient setup). Estimates of the coefficients for these interaction terms are generally significant[9]. When they are, it is an indication that some industry characteristics (e.g. energy intensity) influence how energy-price shocks affect TFP. As for fixed effects, an F-test rejects the null hypothesis that the country × industry dummies are all equal, suggesting time-invariant heterogeneity in terms of efficiency.

Our results indicate that in roughly 69.5% of the cases, the indirect effect outweigh the direct one. Rewriting equation 4 with our estimation results leads to the following formula for estimating the partial elasticity of TFP to energy prices (i.e. the net partial effect) for a given manufacturing sector:

$$\frac{\partial \ln TFP_{ic}}{\partial \ln PRICE_c} = \hat{\alpha}_1 + \hat{\gamma}_i + \hat{\alpha}_{7,c} \ln\left(R\&D_{ic}\right) \qquad (5)$$

where hats denote coefficient estimates. $R\&D_{ic}$ is the time average of R&D expenditures for industry *i* located in country *c* (which is why the time index is omitted). Illustrating the mechanism with one example, in the case of Belgium's chemical sector, when energy prices go up by 10%, the -39.9% (=-47.5%+7.6%) direct effect on TFP changes to a +3.4% overall effect (direct and indirect). This seems to pick up adaptation processes that generated unforeseen gains (if they had been foreseen, they would have been uncorrelated to energy price shocks).

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9 For the sake of conciseness, we have not included these estimation results in *Table 7*. They are shown in Appendix 2.

6.2 Graphical presentation of the results

Our key findings are displayed in *Figure 2*. Each point in the scatter plot of mean R&D spending on the log scale (i.e. arithmetic mean of the logarithm transformed values of R&D spending) against the estimated net partial effect (i.e. estimated overall effect of higher energy prices on TFP) represents an industry × country pair. In this graph, points are coloured differently depending on the sign taken by the net partial effect. Furthermore, histograms of R&D spending averages and net partial effects have been appended to the scatter plot.

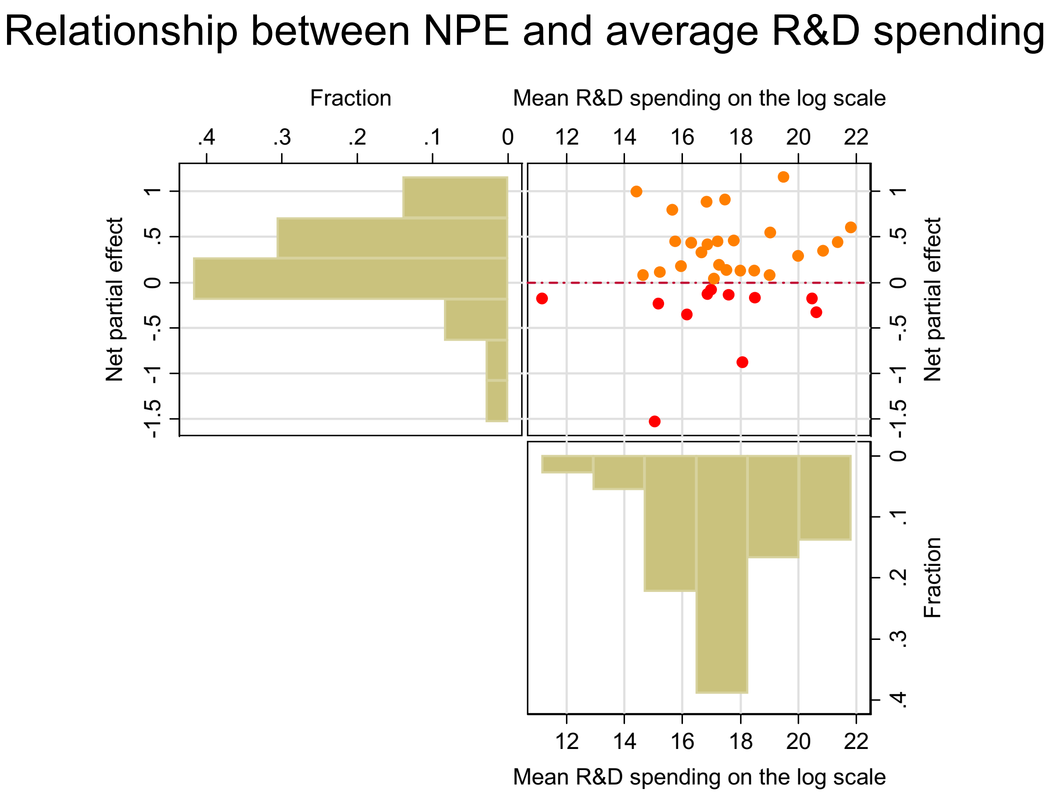

Figure 2 *: Histograms of Net Partial Effects (NPE) and R&D spending averages (on the log scale) along with their scatter plot for the whole sample.*

Figure 2 shows that higher energy prices have a beneficial impact on TFP for the majority of the manufacturing sectors included in our sample. As indicated previously, the net partial effect is positive in 69.5% of the cases. In fact, *Figure 2* tells us much more. First, it reveals us how net partial effects are distributed. Our results indicate that positive values of the net partial effect range between 0.04 and 1.15 with the bulk of positive net partial effects being contained in the interval between 0.04 and 0.55. On their sides, negative values of the net partial effect range between -0.08 and -1.53 with the bulk of negative net partial effects being contained in the interval between -0.08 and -0.36. Second, the large variation in R&D expenditures between manufacturing sectors (cf. Appendix 1: Summary statistics) allows us visually gauging how it influences values of the net partial effect. Though the scatter plot displays a positive trend between mean R&D spending values and net partial effects, one can observe that sectors with the strongest positive impacts of energy price shocks on productivity are generally different from sectors with the (on average) largest investments in R&D expenditures. Alternatively, sectors with the strongest negative impacts of energy price shocks on productivity are generally different from sectors with the (on average) lowest investments in R&D expenditures. As shown in equation 3, these features arise from our model specification where levels of R&D spending do not uniquely determine values of the partial elasticity of TFP to energy prices.

In order to discuss our findings with more ease, the next figures present our results where manufacturing sectors classified at the 2 digit level of ISIC Rev.3 have been grouped together in three broad areas: Chemical, rubber, plastics and fuel products; Electrical, optical and transport equipment; Others. Given this division, *Figure 3* presents our results for the sectors contained in our sample that produce chemical, rubber, plastics or fuel products.

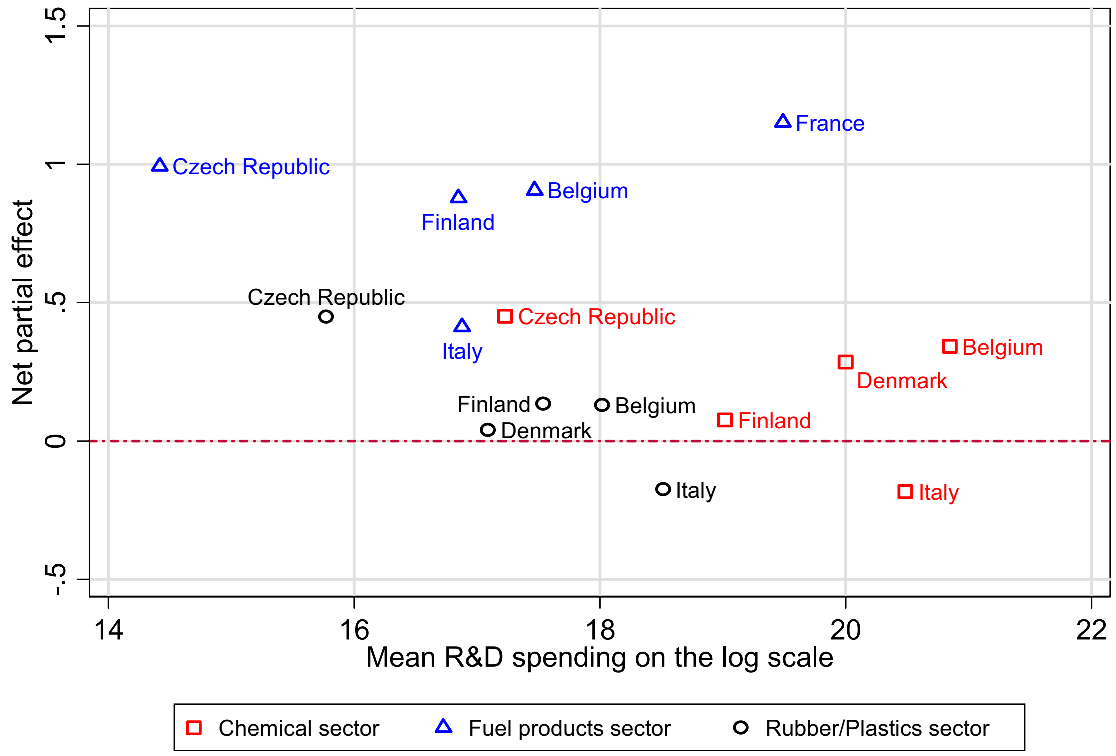

Figure 3 *: Scatter plot of the mean R&D spending on the log scale against the net partial effect. Each symbol in the scatter plot represents an industry × country pair. Different symbols and colours are used for different industries whereas the label indicates the country where the industry is located. Industry names in the legend are abbreviated (cf. Appendix 3: Industry name). Only sectors pertaining to chemical, rubber, plastics or fuel production are displayed.*

All but two sectors in the area of chemical, rubber, plastics and fuel production have improved their productivity as a consequence of higher energy prices. This means that the net partial effect is positive in 86.7% of the cases, against 69.5% for the whole sample. The positive net partial effects range between 0.04 and 1.15 whereas the two negative values of the net partial effect are roughly equal to -0.18. Surprisingly, it is a rather negative relationship between R&D spending and the net partial effect that emerges from visualizing the scatter plot. However, this pattern is misleading as it arises both from differences in the term $\hat{\alpha}_1 + \hat{\gamma}_i$ between industries and from differences in the estimated coefficient $\hat{\alpha}_{7,c}$ between countries. Indeed, the direct effect of higher energy prices on TFP is significantly smaller (in absolute term) for the coke, refined petroleum products and nuclear fuel sector (i.e. referred below as the fuel products sector) than for the other two sectors.[10] Also, the positive estimated coefficient $\hat{\alpha}_{7,c}$ used to compute the indirect effect of higher energy prices on TFP is significantly higher for the Czech Republic than for the other countries.[11] Both effects combine to give relatively high estimates of the net partial effect for sectors characterized by relatively low average level of R&D expenditures. Looking at *Figure 3*, one can observe that, for a given country, the net partial effect is bigger in the fuel products sector than in the other two sectors despite smaller average level of R&D expenditures. In the same way, one can observe that, for a given industry, the net partial effect is bigger in the Czech Republic despite smaller average level of R&D expenditures compared to the other countries.[12]

The overall effect of rising energy prices is higher in the chemical sector than in the rubber and plastics products sector provided that the level of R&D expenditures is significantly larger in the former sector. When the difference is not so important between levels of R&D expenditures, the net partial effects in the rubber and plastics products sectors slightly outweigh the net partial effects in the chemical sector.

As mentioned previously, there are two sectors with a negative net partial effect. Both are located in Italy. It seems that the adaptive capacity associated to a given level of R&D expenditures is smaller in Italy than in the other five countries included in our sample. As explained previously, the reverse is true for the Czech Republic. Again, *Figure 3* clearly shows that the net partial effect estimated for an industry located in the Czech Republic generally exceeds the net partial effect estimated for the same industry in another country.

The second broad area where manufacturing sectors have been grouped together is the production of electrical, optical and transport equipment. Results for this area are shown in *Figure 4*.

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[10] More precisely, the negative direct effect of energy prices on TFP is equal to -2.73 for the fuel products sector whereas it is equal to -3.62 for the Rubber/Plastics sector and to -3.99 for the chemical sector.

[11] From *Table 7*, we can see that the estimated country-specific coefficient $\hat{\alpha}_{7,c}$ is equal to 0.258 for the Czech Republic. Other estimated values taken by this country-specific coefficient are as follows (in descending order): 0.214 (Denmark and Finland), 0.208 (Belgium), 0.199 (France), 0.186 (Italy).

[12] Still, there is one exception to this statement. Estimate of the net partial effect for the French fuel products sector is bigger than for the Czech fuel products sector.

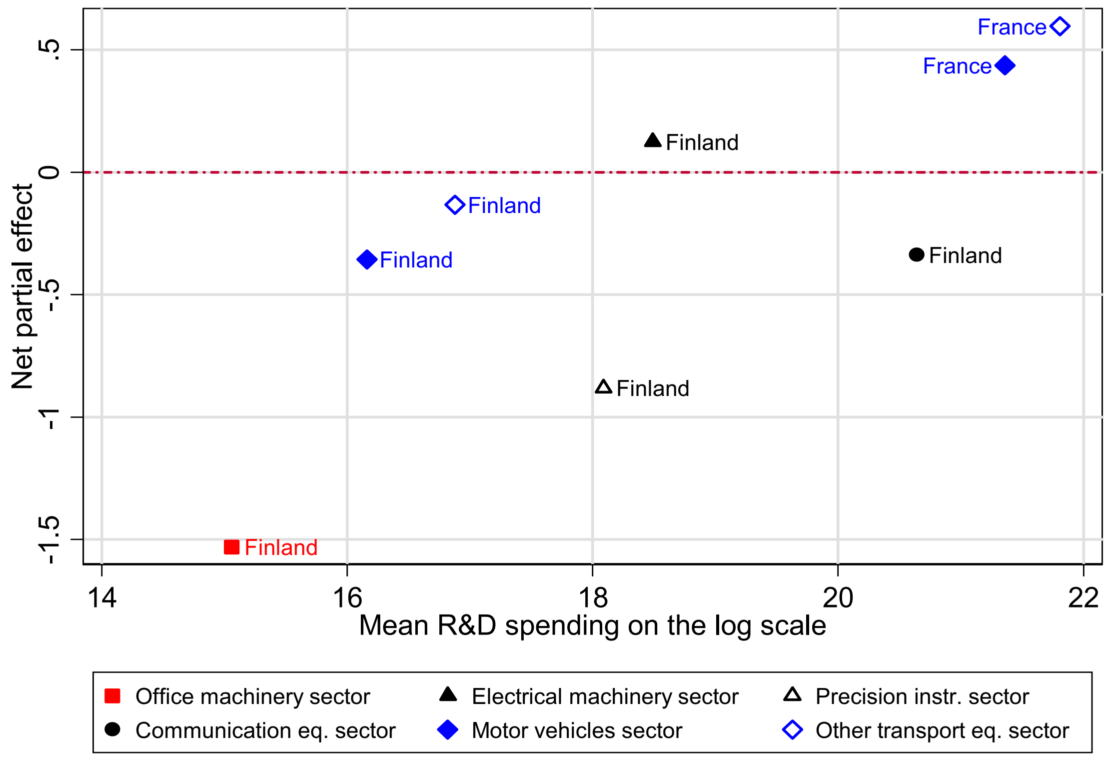

Figure 4 *: Scatter plot of the mean R&D spending on the log scale against the net partial effect. Each symbol in the scatter plot represents an industry × country pair. Different symbols and colours are used for different industries whereas the label indicates the country where the industry is located. Industry names in the legend are abbreviated (cf. Appendix 3: Industry name). Only sectors pertaining to the production of electrical, optical or transport equipment are displayed.*

For the most part, net partial effects estimated for sectors producing electrical, optical or transport equipment are negative. Five Finnish manufacturing sectors provide examples where the positive indirect effect does not outweigh the negative direct one: the net partial effect for these sectors ranges between -0.13 and -1.53. The net partial effect reaches the value of -0.88 for the (Finnish) medical, precision and optical instruments sector and the value of -1.53 for the (Finnish) office, accounting and computing machinery sector. In both cases, the value taken by the net partial effect is markedly low. This result mainly arises because our model has pinned down large negative direct effect of energy prices on these two sectors' TFP. Results obtained for the transport equipment sectors are contrasted. Net partial effects estimated for the French sectors are positive whereas they are negative for the Finnish sectors.[13] Insufficient adaptive capacity of the Finnish transport equipment sectors, as measured by low levels of R&D expenditures compared to the French sectors, explains this difference.

[13] A careful reader may find somewhat peculiar that Finland possesses a motor vehicles, trailers and semi-trailers industry. Actually, production processes leading to the creation of complex final consumer goods such as cars are often split between many different countries. As a matter of fact, Switzerland also has its share in these productions. For instance, more than 300 Swiss firms, with roughly 34'000 employees, are active in sectors pertaining to the car industry (Credit Suisse 2009).

Results for the third broad area of manufacturing activities are shown in *Figure 5*:

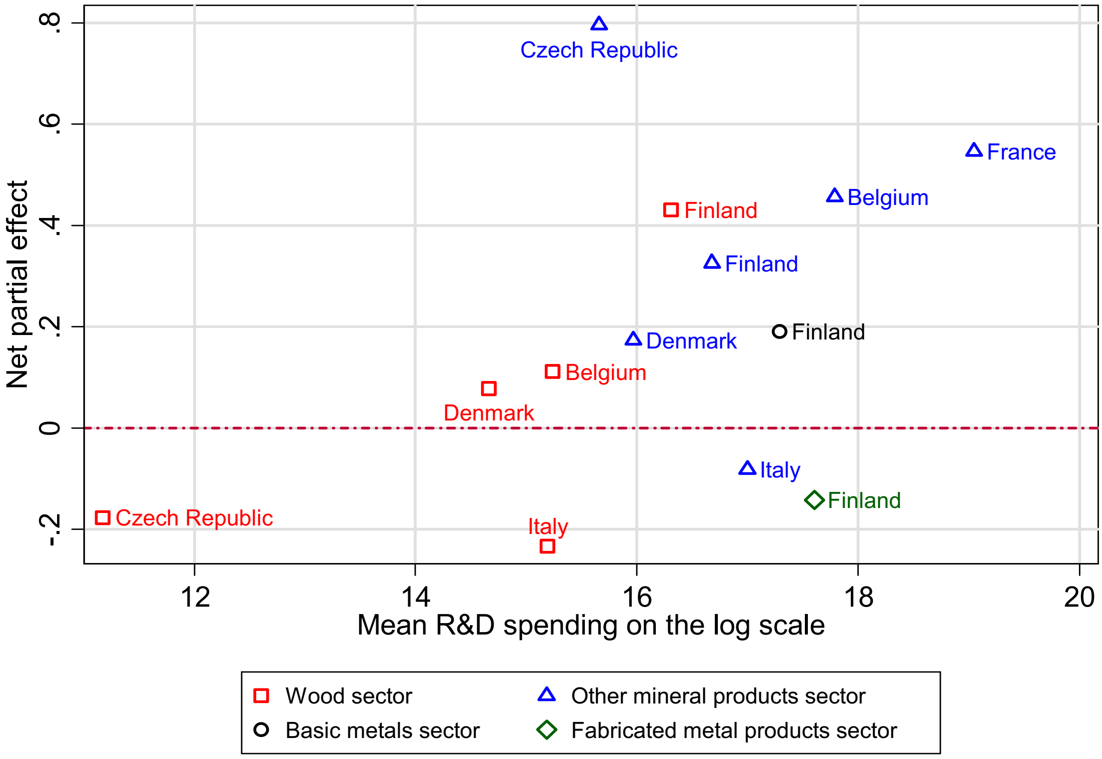

Figure 5 *: Scatter plot of the mean R&D spending on the log scale against the net partial effect for the remaining sectors included in our sample. Each symbol in the scatter plot represents an industry × country pair. Different symbols and colours are used for different industries whereas the label indicates the country where the industry is located. Industry names in the legend are abbreviated (cf. Appendix 3: Industry name).*

More than two-thirds of the remaining sectors included in our sample have improved their productivity as a consequence of higher energy prices. Positive values of the net partial effect range between 0.08 and 0.80 whereas its negative values range between -0.08 and -0.23. R&D spending varies widely in this third broad area of manufacturing activities where one industry × country pair displays an especially low level of reported R&D spending. *Figure 5* identifies this sector as being the Czech wood sector. In fact, it is the sector with the lowest level of R&D spending of our entire sample. From *Figure 5*, it is also visible that, whatever the country, the wood and products of wood and cork sector is characterized by a lower level of R&D activities compared to the other three sectors. This is even the case in Finland despite its economical importance. As a result, a rise in energy prices produces a small positive or even a negative overall impact effect on the wood sector's TFP: confronted to higher energy prices, the wood sector is disadvantaged due to a weak adaptive capacity to new conditions. The conclusions are not similar for the other non-metallic mineral products sector where TFP decreases as a consequence of higher energy prices in only one out of six countries. Moreover, the positive net partial effects can be large.

All in all, the overall effect of higher energy prices on TFP is positive for 69.5% of the national manufacturing sectors included in our sample. The strongest positive impacts of energy price shocks on productivity have been identified for the coke, refined petroleum products and nuclear fuel sector as well as for the other non-metallic mineral products sector. At the other end, we have pinned down the largest negative impacts for the office, accounting and computing machinery sector as well as for the medical, precision and optical instruments sector. Only relatively small positive impact effects or negative ones have been found for the wood and products of wood and cork sector.

6.3 Impact effect on Swiss industries

As indicated in the section describing the data, Swiss manufacturing sectors are not part of our sample due to a lack of data. As a result, data from these sectors are not used in our attempt to pin down the empirical relationship between a manufacturing sector's TFP and energy prices. Missing Swiss R&D data even impede using directly equation 5 which allows deriving an estimated value of the overall impact effect of higher energy prices on a given manufacturing sector's TFP. Given these constraints, our second best approach for estimating it for a set of Swiss industries is as follows. First, we constructed and estimated several models aimed at explaining R&D expenditures. Our modelling of R&D activities at the industry level is far from being sophisticated as our only aim is to obtain broad estimates of R&D spending for Swiss industries. Appendix 4 provides a brief description of the estimated models with their related regression results. Our preferred model is the one with the highest coefficient of determination (i.e. the highest R-squared). Using this model, we derived estimated values of R&D expenditures for several Swiss manufacturing sectors and introduced these estimates in equation 5. As a result, we obtained a measure of the partial elasticity of TFP to energy prices for each of these sectors.

A concrete example will help understanding these general explanations. Focusing on the Swiss chemical sector, our approach consists first in estimating its level of R&D expenditures for different years using equation A 4.1 given in Appendix 4. The data at our disposal allows us estimating the Swiss chemical sector's yearly R&D spending from 1998 to 2002. The average level of R&D expenditures over this period is estimated to be equal to $1.01*10^9$ US$ of 2000. This average is then introduced in equation 5 in order to compute the partial elasticity of TFP to energy prices. At this point, however, there is a slight complication since the estimated coefficient $\hat{\alpha}_{7,c}$ multiplying the logarithm transformed of the average level of R&D expenditures is country-specific. We overcome these difficulties by averaging these country-specific coefficients and by multiplying the coefficient obtained in this way with the logarithm transformed of the average level of R&D expenditures. Our net partial effect estimate for the Swiss chemical sector is then equal to 0.43. All the results derived for Swiss manufacturing sectors are shown in *Table 8*.

Sector	Average value of predicted R&D spending (in 2000 Euro)	Direct Partial Effect	Indirect Partial effect	**Net Partial Effect**
Wood	$4.23*10^6$	-3.06	3.25	**0.19**
Chemical	$1.01*10^9$	-3.99	4.42	**0.43**
Rubber/Plastics	$4.26*10^7$	-3.62	3.74	**0.12**
Other mineral products	$1.72*10^7$	-3.24	3.55	**0.31**
Basic metals	$1.93*10^7$	-3.51	3.57	**0.06**
Fabricated metal products	$5.16*10^7$	-3.91	3.78	**-0.13**
Electrical machinery	$1.46*10^8$	-3.83	4.00	**0.17**
Communication eq.	$4.25*10^8$	-4.75	4.23	**-0.52**
Precision instr.	$7.89*10^8$	-4.75	4.36	**-0.39**
Motor vehicles	$1.68*10^7$	-3.81	3.54	**-0.27**
Other transport eq.	$1.04*10^8$	-3.74	3.93	**0.19**

Table 8 *: Average value of predicted R&D spending and simulated partial elasticity of TFP with respect to energy prices for a set of 11 Swiss manufacturing sectors.*

Our simulations for Switzerland indicate that the overall effect of higher energy prices on TFP is positive for 7 out of 11 sectors. Positive overall effects range between 0.06 and 0.43. The higher positive overall effect has been estimated for the chemical sector. As for the negative overall effects, they range between -0.52 and -0.13. The stronger negative overall effect has been estimated for the radio, television and communication equipment sector. Absolute values of the estimated overall effects are therefore relatively modest, especially when the estimated overall effects are positive.

6.4 Regression results with a lagged effect

Working with static models rather limits our scope to fully verify the Porter hypothesis since its core idea relies on a dynamic process. By inducing innovation, the shocks generated by environmental regulation adopted today will affect firms' productivity tomorrow. In this section, we therefore concentrate on dynamic models by estimating models with a lagged value of energy price. Regression results for these models are shown in the following table.[14]

[14] The random effects estimator degenerates again into the pooled OLS estimator. This is the reason why only estimation results obtained with the pooled OLS estimator and the fixed effects estimator are shown in *Table 9*. Moreover, regression results obtained for the interaction terms "energy price $\times$ industry dummy" are presented in Appendix 2.

Variable	Pooled OLS	Pooled OLS	Fixed effects
XPROD	*0.020*	*0.024*	*-0.003*
	(0.65)	*(1.15)*	*(0.15)*
MPEN	*0.002*	*-0.007*	*-0.015*
	(0.76)	*(-3.51)******	*(4.26)******
LABEMPM	*-0.007*	*-0.080*	*0.020*
	(-0.72)	*(-1.23)*	*(0.44)*
R&D	*-0.634*	*-0.806*	*-1.366*
	*(-1.81)**	*(-2.66)****	*(3.45)******
PROD	*0.138*	*-0.118*	*0.722*
	(1.38)	*(-0.86)*	*(5.88)******
$PRICE_t$	*-1.855*	*-4.139*	*-5.344*
	(-1.67)	*(-2.63)****	*(3.99)******
$PRICE_{t-1}$	*0.329*	*0.200*	*0.375*
	(1.08)	*(1.03)*	*(2.47)****
ESTAB	*-0.034*	*-0.059*	*-0.048*
	(-0.79)	*(-2.49)****	*(1.89)**
EXRATE	*0.003*	*0.764*	*0.666*
	(0.03)	*(1.41)*	*(1.75)**
Price*XPROD	*-0.003*	*-0.003*	*0.003*
	(-0.61)	*(-0.92)*	*(0.68)*
Price*LABEMPM	*0.001*	*0.015*	*-0.005*
	(1.04)	*(1.31)*	*(0.57)*
Price*R&D*dummy BE	*0.113*	*0.182*	*0.247*
	*(1.81)**	*(3.65)******	*(3.50)******
Price*R&D*dummy CZ	*0.114*	*0.163*	*0.309*
	*(1.75)**	*(3.13)******	*(3.83)******
Price*R&D*dummy DK	*0.115*	*0.155*	*0.249*
	*(1.80)**	*(3.12)******	*(3.45)******
Price*R&D*dummy FI	*0.115*	*0.171*	*0.250*
	*(1.83)**	*(3.34)******	*(3.55)******
Price*R&D*dummy FR	*0.114*	*0.124*	*0.237*
	*(1.83)**	*(2.41)****	*(3.61)******
Price*R&D*dummy IT	*0.108*	*0.133*	*0.222*
	*(1.75)**	*(2.52)****	*(3.54)******
Constant	*5.560*	*20.377*	*4.644*
	(1.29)	*(2.82)******	*(0.63)*
Price*Sector dummies	*Yes*	*Yes*	*Yes*
Sector dummies	*No*	*Yes*	*No*
Country dummies	*No*	*Yes*	*No*
Industry*Country pair dummies	*No*	*No*	*Yes*
Year dummies	*Yes*	*Yes*	*Yes*
R^2 adj.	*0.53*	*0.64*	*0.82*
Nbr of obs.	*317*	*317*	*317*

Table 9 *: This table presents the total factor productivity regression results using pooled OLS and fixed effects estimators. Compared to Table 7, all model specifications add the lagged value of energy price in the set of regressors. Robust t- and z-statistics are given in parenthesis (Cluster-robust standard errors are computed whenever the pooled OLS estimator is used). The meaning of the number of stars is as follows: * coefficient estimate significant at the 10% level; ** significant at the 5% level; *** significant at the 1% level. Country names are abbreviated in the following way: BE=Belgium, CZ=Czech Republic, DK=Denmark, FI=Finland, FR=France, IT=Italy.*

As for the static case, our view of the fixed effects as being potentially correlated with the explanatory variables prompts us to focus on the estimation results obtained with the fixed effects estimator. A quick comparison of *Table 7* with *Table 9* shows that adding the lagged value of energy price as a regressor to our model alters only slightly the estimation results. In general, however, a rise in energy prices becomes less favourable to productivity contemporaneously. Nonetheless, the coefficient of the lagged 1 year energy price variable is both positive and significant. Furthermore, its magnitude is not negligible: the partial elasticity of TFP to lagged 1 year energy prices is equal to 0.375. In other words, a 10% rise in energy prices today causes a 3.75% rise in TFP tomorrow. This important result shows that industries faced with energy price shocks require more than one year adapting their production processes.

Econometrically, it is worth emphasizing the fact that the lagged treatment variable is not interacted with any measure of adaptive capacity at the industry × country level. Therefore, its impact effect is the same across industries, whatever the level of R&D spending. Different explanations can be given as to the source of its positive sign. First, it is unlikely that R&D activities triggered by energy prices shocks have a contemporaneous influence on productivity. Our result then suggests that induced innovation displays its effect on productivity only after a one year lag. Another way to understand this result is to think of firms with limited adaptive capacity to adopt measures taken by those with a higher adaptive capacity with a one year delay. This is a plausible explanation if we believe that some sorts of diffusion mechanism are at work within and across industries.

7 Conclusion

Our results are about the reaction of industry-level TFP to energy-price shocks rather than to specific changes in environmental regulation. As such, they provide only indirect evidence on the effect of environmental regulations. However, as we showed in the paper's descriptive section, variations in energy prices, both over time and across countries, carry information on national energy taxation choices that are directly relevant to the debate on the cost of environmental regulations.

With this caveat, by and large our results lend support to the Porter Hypothesis and provide a clue to the underlying mechanism. On the basis of a large panel of industries tracked for most OECD countries over a long period, we find that (i) rising energy prices reduce TFP at the industry level, but (ii) when interacted with R&D spending, the effect is positive, significant, and strong enough to produce a positive net effect for most industries. The inclusion of a full set of industry × country fixed effects ensures that the measured effect is "within-industry" and not driven by unobserved heterogeneity.

Because the effect is contemporaneous, it is unlikely to be driven by R&D itself. Rather, it is likely that R&D spending proxies for the reactivity of management to energy-price shocks and for the active search for more efficient processes, whether through true knowledge creation, knowledge absorption, or better organization. Could it be driven by a selection effect? In the long run, in a heterogeneous-firm setting, higher energy prices are likely to induce the exit of the least productive firms in each industry; in addition, only the most productive ones could afford the fixed cost of higher R&D spending. Thus, energy-price shocks would generate a partition of firms, with the most productive doing more R&D (or starting to do R&D), the middle ones simply suffering reduced profitability, and the least productive ones exiting. This would produce a rise in industry-wide average productivity. Only firm-level analysis could tell whether this selection (between-firm) process is at play and whether it is the most important quantitatively. However, it is a long-run phenomenon that is unlikely to be driving the contemporaneous effects that we identify so strongly in the industry-level data.

The nature of the results described above was not altered when we estimated a dynamic rather than a static model. The dynamic specification differs from the static one by the inclusion of a lagged 1 year energy price variable whose effect on industry TFP was found to be positive. This result provides additional insights as to the underlying mechanism being at work. It suggests a sort of adjustment between industries where low-tech industries learn from measures (or even adopt measures) that have been undertaken in the more reactive ones. It might also suggest that some innovation is induced that reduces, with a one year delay, the detrimental impact of rising energy prices on TFP.

The policy implications of our findings are straightforward. Emission-regulation shocks, inasmuch as they raise the cost associated with the use of fossil fuels, can be expected to have a negative direct effect on TFP but a positive one for those industries with the highest capacity to adapt, as proxied by their R&D spending. This suggests a policy aimed at improving the capacity of firms to adapt through R&D incentives *prior* to the adoption of stiff emission standards. If effective, R&D incentives could turn subsequent environmental regulation into the kind of win-win that Porter and van der Linde described with their case studies.

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Appendix 1: Summary statistics

A 1.1 Basic information on summary statistics

A few words are required to interpret correctly the summary statistics given in this appendix. In a panel data setting, a variable displays variation both across time and across entities. In other words, its overall variation can be decomposed into within and between variations. The latter two variations are summarized by the within and between standard deviations (column labelled "Std. Dev."). The column labelled "Mean" gives the grand mean of the variables. When variables are in logs, the geometric mean is also given. Signification of the min and max columns depends on the dimension of the data that is considered. "Overall" min and max values refer to overall minimum and maximum values in the sample. "Between" min and max values refer to minimum and maximum of the entity-specific time-averaged values (i.e. the within-group means) of the variables. Eventually, "Within" min and max values refer to minimum and maximum values of a transformed variable obtained by subtracting the within-group mean and then adding back in the grand mean to the original variable (this transformation is applied to the data when the *xtreg, fe* command is used in Stata).

A 1.2 Summary statistics for variables in logs

Variable		Mean (Geometric mean)	Std. Dev.	Min	Max
TFP	Overall	*-0.23 (0.79)*	*0.35*	*-2.40*	*1.28*
	Between		*0.27*	*-0.74*	*0.58*
	Within		*0.23*	*-2.22*	*1.22*
R&D	Overall	*17.53 (4.1*10⁷ US$ of 2000)*	*2.22*	*9.96*	*22.24*
	Between		*2.20*	*11.17*	*21.81*
	Within		*0.44*	*15.80*	*20.86*
PRICE	Overall	*5.66 (287.1 US$ of 2000/1000 litres)*	*0.39*	*5.12*	*6.49*
	Between		*0.33*	*5.34*	*6.41*
	Within		*0.16*	*5.35*	*5.97*
PROD	Overall	*22.50 (5.9*10⁹ US$ of 2000)*	*1.36*	*18.10*	*25.15*
	Between		*1.28*	*19.74*	*24.78*
	Within		*0.27*	*20.86*	*23.67*
ESTAB	Overall	*6.82 (916 establishments)*	*1.89*	*1.95*	*10.84*
	Between		*1.80*	*2.43*	*10.02*
	Within		*0.56*	*3.88*	*7.83*
EXRATE	Overall	*0.62 (1.86 Nat. Cur./US$)*	*1.29*	*-0.45*	*3.65*
	Between		*1.31*	*-0.12*	*3.46*
	Within		*0.13*	*0.29*	*0.85*

Table A 1.1 *: Summary statistics for the variables transformed with the natural logarithm (derived using Stata 10). The sample is constituted of 322 observations. Our unbalanced data include repeated observations for 36 manufacturing sectors.*

Among the variables in logs, we can observe a considerably greater overall variability in R&D expenditures (*R&D*), in the value of output (*PROD*), in the number of establishments (*ESTAB*) and in exchange rates (*EXRATE*) than in total factor productivity (*TFP*) or in energy prices (*PRICE*). For the former variables, their (relatively) high overall variability is mainly due to a large variability across sectors. The fact that R&D expenditures vary widely across different sectors is not surprising given that R&D activities depend fundamentally on several industry-specific characteristics as well as on the industry's size. Though much smaller, within industry variation is also important for R&D expenditures. The latter type of variation is also important for variables such as energy prices and total factor productivity. In fact, these two variables are characterized by a (relatively) higher participation of within variability to overall variability.

A 1.3 Summary statistics for variables representing percentages

Variable		Mean	Std. Dev.	Min	Max
XPROD	Overall	*50.18*	*46.22*	*4.99*	*424.58*
	Between		*41.51*	*7.47*	*208.37*
	Within		*23.95*	*-75.19*	*266.39*
MPEN	Overall	*43.07*	*29.86*	*7.01*	*155.27*
	Between		*33.53*	*8.03*	*145.60*
	Within		*5.20*	*23.58*	*68.10*
LABEMPM	Overall	*112.65*	*30.48*	*50.67*	*209.34*
	Between		*31.42*	*52.21*	*194.72*
	Within		*5.02*	*92.42*	*144.97*

Table A 1.2 *: The table displays summary statistics for the set of variables representing percentages (derived using Stata 10). The sample is constituted of 322 observations. Our unbalanced data include repeated observations for 36 manufacturing sectors.*

Among the variables representing percentages, we can observe a stronger overall variability for the share of exports in production (*XPROD*). A striking feature of variability for these variables is that the within variation is small compared to the between sector variation. This is particularly the case for the labour compensation per employee relative to total manufacturing (*LABEMPM*) and import penetration (*MPEN*) variables. It is an indication that estimators using within variation (like the fixed effects estimator) will probably experience difficulties pinning down effects of these variables on the dependent variable.

Appendix 2: Additional regression results

A 2.1 Estimation results for the "energy price × industry dummy" terms in the static setting

Manufacturing sector	**Pooled OLS**	**Pooled OLS**	**Fixed effects**
Wood and products of wood and cork	*-0.048* *(-0.73)*	*0.137* *(0.26)*	*1.694* *(3.50)******
Coke, refined petroleum products and nuclear fuel	*-0.112* *(-1.18)*	*-1.376* *(-1.53)*	*2.026* *(2.77)******
Chemicals and chemical products	*-0.155* *(-5.42)******	*-0.709* *(-1.45)*	*0.758* *(1.99)****
Rubber and plastics products	*-0.072* *(-1.88)**	*-0.248* *(-0.49)*	*1.134* *(2.65)******
Other non-metallic mineral products	*-0.060* *(-1.02)*	*0.095* *(0.20)*	*1.509* *(3.30)******
Basic metals	*-0.148* *(-3.07)******	*-0.749* *(-2.15)****	*1.244* *(2.80)******
Fabricated metal products, except machinery and eq.	*-0.012* *(-0.31)*	*-0.710* *(-2.20)****	*0.842* *(2.12)****
Office, accounting and computing machinery	*-0.141* *(-2.23)******	*-3.906* *(-5.32)******	*-1.419* *(0.81)*
Electrical machinery and apparatus, n.e.c.	*-0.040* *(-1.51)*	*-0.465* *(-1.50)*	*0.920* *(2.29)****
Medical, precision and optical instruments	*0.022* *(0.54)*	*-0.731* *(-2.16)****	*0.596* *(1.45)*
Motor vehicles, trailers and semi-trailers	*-0.116* *(-2.56)****	*0.676* *(0.87)*	*0.939* *(1.79)**
Other transport eq.	*-0.063* *(-1.28)*	*-0.222* *(-0.42)*	*1.009* *(2.20)****
Nbr of obs.	*322*	*322*	*322*

Table A 2.1 : *This table is a complement to Table 7. It presents the coefficient estimates for the interaction terms "energy price × industry dummy" in the total factor productivity regressions. Robust t- and z-statistics are given in parenthesis (Cluster-robust standard errors are computed whenever the pooled OLS estimator is used). The meaning of the number of stars is as usual: * coefficient estimate significant at the 10% level; ** significant at the 5% level; *** significant at the 1% level.*

A 2.2 Estimation results for the "energy price × industry dummy" terms in the dynamic setting

Manufacturing sector	Pooled OLS	Pooled OLS	Fixed effects
Wood and products of wood and cork	-0.071 (-1.36)	0.239 (0.47)	1.739 (3.41)***
Coke, refined petroleum products and nuclear fuel	-0.147 (-1.92)*	-1.359 (-1.40)	2.361 (3.03)***
Chemicals and chemical products	-0.158 (-6.57)***	-0.842 (-1.99)*	0.773 (1.92)*
Rubber and plastics products	-0.078 (-2.43)**	-0.317 (-0.72)	1.173 (2.62)***
Other non-metallic mineral products	-0.076 (-1.54)	0.025 (0.06)	1.534 (3.16)***
Basic metals	-0.167 (-4.56)***	-0.773 (-2.55)**	1.367 (2.75)***
Fabricated metal products, except machinery and eq.	-0.025 (-0.74)	-0.616 (-2.26)**	0.868 (2.09)**
Office, accounting and computing machinery	-0.164 (-3.46)***	-4.210 (-6.67)***	-1.256 (0.70)
Electrical machinery and apparatus, n.e.c.	-0.048 (-2.24)**	-0.510 (-1.89)*	0.932 (2.17)**
Medical, precision and optical instruments	0.010 (0.27)	-0.795 (-2.64)**	0.618 (1.39)
Motor vehicles, trailers and semi-trailers	-0.129 (-3.64)***	0.407 (0.60)	0.934 (1.69)*
Other transport eq.	-0.079 (-1.93)*	-0.299 (-0.69)	1.048 (2.12)**
Nbr of obs.	317	317	317

Table A 2.2 : *This table is a complement to Table 9. It presents the coefficient estimates for the interaction terms "energy price × industry dummy" in the total factor productivity regressions with a lagged effect of energy price. Robust t- and z-statistics are given in parenthesis (Cluster-robust standard errors are computed whenever the pooled OLS estimator is used). The meaning of the number of stars is as usual: * coefficient estimate significant at the 10% level; ** significant at the 5% level; *** significant at the 1% level.*

Appendix 3: Industry name

Industry name according to the ISIC Rev.3 classification at the 2 digit level	**Abbreviation used in the report**
Wood and products of wood and cork	Wood sector
Coke, refined petroleum products and nuclear fuel	Fuel products sector
Chemicals and chemical products	Chemical sector
Rubber and plastics products	Rubber/Plastics sector
Other non-metallic mineral products	Other mineral products sector
Basic metals	Basic metals sector
Fabricated metal products, except machinery and equipment	Fabricated metal products sector
Office, accounting and computing machinery	Office machinery sector
Electrical machinery and apparatus, n.e.c.	Electrical machinery sector
Radio, television and communication equipment	Communication eq. sector
Medical, precision and optical instruments	Precision instr. sector
Motor vehicles, trailers and semi-trailers	Motor vehicles sector
Other transport equipment	Other transport eq. sector

Table A 3.1 *: The table indicates how the names of industries are (often) abbreviated in subsections 6.2 and 6.3. The original industry name is given by the ISIC Rev.3 classification (sectors at the 2 digit level).*

Appendix 4: R&D spending regression results

Our modelling of R&D spending is as follows:

$$\ln(R\&D_{ict}) = \beta_0 + \beta_1 \ln(VALU_{ict}) + \beta_2 \ln(ESTAB_{ict}) + \beta_3 MPEN_{ict} + \Delta + \varepsilon_{ict} \quad \text{(A 4.1)}$$

The variable $VALU_{ict}$ refers to value added at basic price (in US$ of 2000). It controls for scale effects. Both $ESTAB_{ict}$ and $MPEN_{ict}$ are already known from the previous regressions. They control for the effects of different competitive environments on R&D activities. Finally, Δ symbolises a set of fixed effects. The next table shows regression results for three different models that only differ through the term Δ.

Variable	Pooled OLS	Pooled OLS	Pooled OLS
VALU	*1.406*	*1.403*	*1.242*
	*(42.19)******	*(41.11)******	*(45.47)******
ESTAB	*-0.338*	*-0.329*	*-0.389*
	*(12.35)******	*(11.65)******	*(13.03)******
MPEN	*0.023*	*0.023*	*-0.001*
	*(19.09)******	*(18.96)******	*(1.31)*
Constant	*-10.899*	*-10.873*	*-7.610*
	*(15.60)******	*(13.74)******	*(12.83)******
Sector dummies	*No*	*No*	*Yes*
Year dummies	*No*	*Yes*	*Yes*
R^2	*0.62*	*0.62*	*0.85*
R^2 adj.	*0.62*	*0.62*	*0.85*
Nbr of obs.	*1122*	*1122*	*1122*

Table A 4.1 : *This table presents the R&D spending regression results using pooled OLS. Differences between the three models arise from differences in the set of fixed effects used in each regression.*

In order to predict R&D expenditures, our preferred model is the one with the highest coefficient of determination (i.e. the highest R-squared). This means that our preferred model is the one that includes both industry and time fixed effects. Consequently, the following equation will be used to predict the level of R&D expenditures for Swiss manufacturing sectors:

$$PREDICT_{ict} = -7.610 + 1.242 \ln(VALU_{ict}) - 0.389 \ln(ESTAB_{ict}) - 0.001 MPEN_{ict} + \hat{\Delta} \quad \text{(A 4.2)}$$

Where $PREDICT_{ict}$ is the predicted value of $R\&D_{ict}$ (in logs).