Fondazione Eni Enrico Mattei

NOTA DI LAVORO

103.2013

The Effect of Within-Sector, Upstream and Downstream Energy Taxes on Innovation and Productivity

By **Chiara Franco**, Catholic University
Giovanni Marin, Ceris-CNR, Institute for Economic Research on Firms and Growth, National Research Council of Italy

Energy: Resources and Markets
Series Editor: Giuseppe Sammarco

The Effect of Within-Sector, Upstream and Downstream Energy Taxes on Innovation and Productivity

By Chiara Franco, Catholic University
Giovanni Marin, Ceris-CNR, Institute for Economic Research on Firms and Growth, National Research Council of Italy

Summary

The aim of the paper is to investigate the effect of environmental stringency on innovation and productivity using a cross-country panel made up of 7 European countries for 13 manufacturing sectors over the years 2001-2007. This research topic goes under the heading of Porter Hypothesis (PH) of which different versions have been tested. We take into consideration both the strong and the weak versions while adding some peculiarities to the analysis. Firstly, we assess the role played by a specific environmental regulation, that is energy taxes, that have rarely been empirically tested as factors that can favour PH hypothesis to be verified. Secondly, we do not consider, within the same framework, only the effect of energy taxes in the same sector (within-sector), but also the role played by energy taxes in upstream and downstream sectors in terms of input-output relationship. Thirdly, we test these relationships also "indirectly" by verifying whether innovation can be one of the channels through which higher sectoral productivity can be reached. The main findings suggest that downstream stringency is the most relevant driver for innovation and that most of the effect of regulation on productivity is direct, while the part of the effect mediated by induced innovation is not statistically significant.

Keywords: Energy Taxes, Porter Hypothesis, Upstream, Downstream

JEL Classification: L6, O13, Q55

Address for correspondence:

Giovanni Marin
National Research Council of Italy
Via Bassini 15
20133 Milano
Italy
E-mail: g.marin@ceris.cnr.it

The Effect of Within-Sector, Upstream and Downstream Energy Taxes on Innovation and Productivity

Chiara Franco* Giovanni Marin†

Abstract

The aim of the paper is to investigate the effect of environmental stringency on innovation and productivity using a cross-country panel made up of 7 European countries for 13 manufacturing sectors over the years 2001-2007. This research topic goes under the heading of Porter Hypothesis (PH) of which different versions have been tested. We take into consideration both the strong and the weak versions while adding some peculiarities to the analysis. Firstly, we assess the role played by a specific environmental regulation, that is energy taxes, that have rarely been empirically tested as factors that can favour PH hypothesis to be verified. Secondly, we do not consider, within the same framework, only the effect of energy taxes in the same sector (within-sector), but also the role played by energy taxes in upstream and downstream sectors in terms of input-output relationship. Thirdly, we test these relationships also 'indirectly' by verifying whether innovation can be one of the channel through which higher sectoral productivity can be reached.

The main findings suggest that downstream stringency is the most relevant driver for innovation and that most of the effect of regulation on productivity is direct, while the part of the effect mediated by induced innovation is not statistically significant.

Keywords: Energy Taxes, Porter Hypothesis, Upstream, Downstream

JEL: L6, O13, Q55

*Catholic University of the Sacred Heart of Milan, Italy, e-mail: chiara.franco@unicatt.it.

†Ceris-CNR, Institute for Economic Research on Firms and Growth, National Research Council of Italy, Via Bassini, 15, 20133 Milano, Italy, e-mail: g.marin@ceris.cnr.it.

1 Introduction

The idea that environmental regulation can foster the ability of a country to improve its competitiveness has been proposed by several scholars and has attracted the attention of policy makers. The study of the so called 'Porter Hypothesis' (PH) (Porter and van der Linde, 1995) has revolved around the examination of whether more stringent environmental regulations can improve or hamper better economic performance of firms, sectors or countries. The general idea shared by policy makers and economists is that environmental protection can generate extra costs for firms therefore causing their domestic and international performance to fall. Following this point of view implies that firms have to sustain costs to comply with environmental regulations. For example, if a firm has to pay an environmental tax, this causes higher operating costs which could induce a drop in planned productive investments. On the contrary, in the Porter's idea, pollution can be considered as a waste of resources that, if properly handled, could improve firms' performance. In particular, environmental regulations can give rise to mechanisms leading to offset the additional costs introduced because of the regulation, causing an increase in performance. They could help to signal inefficiencies in the way resources are used, or could create the conditions for regulated actors to exploit first mover advantages once the regulation will be adopted by competitors.

From an empirical point of view, different versions of the PH have been tested. Jaffe and Palmer (1997) distinguish among three different versions, namely the 'narrow', the 'weak' and the 'strong' version of the PH. The first is based on the idea that only certain types of environmental regulations, such as market-based (flexible) environmental regulations (e.g. tradable permits), can foster competitiveness. On the other hand, the weak version argues that environmental regulations (of any kind) can foster innovations, with no *a priori* expectation about the net effect on competitiveness and productivity. Finally, the strong version refers to the fact that environmental regulations, either market-based or standard-based, can lead to improved competitiveness and productivity through innovation induced by the regulation, allowing as a consequence, to more than offset compliance costs. Empirical studies do not reach unanimous findings with respect to proving these effects to be at work. For this reason, in this paper, we dig deeper into this issue by providing empirical evidence on the role played by energy taxes as drivers of innovation and productivity. We focus on the manufacturing sectors of 7 European countries over the period 2001-2007. The importance of investigating the effect for European countries lies not only in the fact that they have been among the first to adopt stricter environmental policies, but also on the lack of comprehensive analysis of the effects of energy taxes on measures of competitiveness based on European countries.

Our contributions to the literature are threefold. In the first place, with the exception of the paper by Leiter et al. (2011), environmental taxes, and in particular, in our case energy taxes, are scarcely investigated as types of regulations potentially inducing PH hypothesis to hold. In the second place, we examine the two versions of the PH: that is, we study the effect of energy taxes on innovation to examine the weak version of the PH and we investigate the extent to which environmental taxes affect productivity (directly and through innovation) to test the strong version of the PH. The peculiarity of our approach lies in the fact that, whereas most of the previous analyses only focuses on the effects generated by environmental stringency in the same sector (e.g. Kneller and Manderson (2012)), we consider both intra and inter-industry effects of stringency measures by means of annual input-output data. Thirdly, we do not only examine the effect considering direct relationships, that is from taxes to innovation or productivity, but we try to shed light on the possibility that innovation activities are one of the indirect channels through which the effect of energy taxes on productivity can become evident.

Our main findings suggest that both the weak and strong version of the PH are confirmed, with our measures of environmental regulatory stringency being positively related to both innovation (induced innovation - weak version of the PH) and productivity (strong version of the PH). The strongest effect appears to be related to downstream regulatory stringency. However, when we investigate the role of innovation as a mediating factor which allows sectors to more than offset the costs of regulation, we find no significant mediation.

The paper is organized as follows. In section 2 we review the relevant empirical and theoretical literature. In section 3 we describe the data. In section 4 we discuss our empirical models. In section 5 we present our results. Section 6 concludes.

2 Literature review

The starting point of the PH focuses on the likely beneficial effects that properly designed environmental regulations can have on competitiveness. In particular, Porter and van der Linde (1995) claim that more stringent environmental policies do not necessarily cause losses of competitiveness. The reason is that environmental regulations may have beneficial effects on production efficiency and technological improvements and they stimulate environmental awareness of firms about different (and more environmentally-friendly) manners to handle the production process. This could result in an increase in environmental regulatory pressure also to firms that are connected to regulated firms through value chains relationships such as customers and suppliers.

The taxonomy of the different versions of the PH proposed by Jaffe and Palmer (1997) highlights three different versions of the PH: the 'weak' version relates to the impact of environmental regulations on firm's innovation activities. Contrasting results have been reached on this side of the issue: in this respect, Jaffe and Palmer (1997), in a sectoral study about US manufacturing sectors, estimate how pollution abatement costs are related to patent applications as well as total R&D expenditures, finding a positive relationship (R&D expenditures increase by 0.15 % due to a pollution abatement cost increase of 1 %). On the other hand, the effect on patent applications is not statistically significant. However, they adopt a broad approach, that is considering not only environmental innovations but all types of innovative output. Differently, the analysis by Brunnermeier and Cohen (2003), analyzing US manufacturing industries over the period 1983–1992, is restricted to environmentally-related patents, for which is found a positive, even though small, relationship. The bidirectional linkages between emissions and innovation activities is studied by Carrion-Flores and Innes (2010) using US sectoral data: the main findings suggest a negative relationship in both directions, even though the effect on long run emission reduction which is induced by innovation is small. Popp (2006) provides evidence that the introduction of environmental regulations on sulphur dioxide (SO2) in the United States, and on nitrogen dioxides in Germany and Japan, was shortly followed by a very significant increase in the number of relevant patents.

A positive effect is also found by Kneller and Manderson (2012), who analyze the case of 25 UK manufacturing industries over the period 2000-2006, considering the role played by expenditure in pollution control in affecting innovation measured with environmental R&D. Thier findings suggest that the positive effects are driven by the crowding out effect of environmental R&D with respect to other types of R&D investments.

Similarly to our cross-country approach, Johnstone et al. (2012) carry out an analysis based on an unbalanced panel of 77 countries over the years 2001 and 2007 using data from the European Patent Office (EPO) World Patent Statistical (PATSTAT) database and the World Economic Forum's (WEF) 'Executive Opinion Survey'. Their findings confirm that higher environmental stringency positively affects environmental innovation.

The strong version of the PH entails the estimation of the effects of environmental regulations on the economic performance of firms, sectors or countries. Also in this case empirical results have produced mixed results. Earlier studies generally did not find evidence of the strong version of the PH. For example, Gollop and Roberts (1983) find that the introduction of regulations to reduce sulphur emissions, targeted at American electrical utilities, caused a decrease in productivity by 43 % in the '70s. Jaffe and Stavins (1995), in their review, analyze some papers which find a negative impact of environmental regulation on productivity.

More recently, a positive effect seems to emerge finding confirmation of the strong version of the PH. Hamamoto (2006) finds that environmental regulations have had a positive effect on productivity in Japanese manufacturing sectors, through positive effects on R&D. Alpay et al. (2002) find that the productivity of the Mexican food processing industry increased following the implementation of more stringent environmental regulations. Lanoie et al. (2008) put forward empirical evidence on the effect that a stringent environmental regulation may have on industrial productivity in 17 Canadian manufacturing industries. They consider a dynamic model finding that the contemporaneous effect of environmental regulation on productivity is negative, but a positive impact is detected when using lagged variables of environmental regulation[1].

All reviewed empirical analyses have in common the investigation of the effect of environmental regulation on innovation, competitiveness and productivity based on the implicit assumption that the inducement effect of environmental regulatory stringency regards only firms, sectors and countries directly targeted by environmental regulations (within-sector regulation). This implicit assumption is straightforward when investigating the adoption of innovations. However, it is reasonable to assume that a wider variety of actors is involved in the phase of invention and development of new or improved technologies aimed at reacting to environmental regulations. Recent theoretical contributions stressed the relevance of suppliers, in

[1]The effect of environmental regulations has not been examined only with respect to productivity but also considering whether they affect investment decisions. Gray and Shadbegian (1998) and Gray and Shadbegian (2003) find that U.S. paper mills investment decisions in less pollutant type of production processes have been caused by more stringent air and water regulations. However, they also detect an overall negative effect on productivity due to the process of diverting those investments from production activities. In the same way, Arimura et al. (2007) recognize that a positive and significant relationship can occur between the stringency of environmental regulations and investment in R&D. Leiter et al. (2011) underlines how environmental regulations, measured by industry's total current expenditures or a country-industry's revenue from environmental taxes, can affect different types of investments such as gross investment in tangible goods, machinery, construction and productive investments. Their findings apply to 9 manufacturing industries examined for 21 European countries over the period 1998-2007.

the form of upstream firms and sectors, as a crucial source of technology to cope with environmental regulations.

In this respect, Greaker (2006) builds a two-sector model in which a stringent environmental regulation affects the polluting industry (downstream) which abates pollution by means of pollution abatement technologies supplied by the pollution abatement service sector (upstream). In this setting, stringent environmental regulation downstream, by boosting the demand for pollution abatement equipment, stimulate innovation and entry in the pollution abatement service sectors.

The model by Greaker and Rosendahl (2008) builds on Greaker (2006) but evaluates the role of R&D in the upstream pollution abatement service sector as well as the export performance of the pollution abatement service sector itself. While the result about the positive effect of a stringent environmental regulation on the competitiveness of the downstream polluting sector remains unchanged, they show that a stringent environmental regulation has an ambiguous effect on the export performance of the pollution abatement service sector. The first best is reached when the stringent environmental regulation is combined with an R&D subsidy.

Finally, Heyes and Kapur (2011) outline a model in which both the regulated polluting firm (downstream) and the specialized supplier of the abatement technology (upstream) perform R&D aimed at obtaining a temporary monopoly (by means of a patent) for the supply of the pollution abatement technology. Even though the objective of their article is to investigate a dynamically optimal level of regulatory stringency, it is the first theoretical contribution explicitly allowing both the polluting firm and the specialized suppliers of pollution abatement technology to perform innovation activities.

These recent theoretical contributions on the role of inter-sectoral linkages in the literature on the PH have no empirical counterpart.

3 Empirical model

[Figure 1 about here]

The empirical approach we adopt here is described by Figure 1. Following Lanoie et al. (2011), we aim at investigating the full chain of causality links between environmental regulatory stringency (here energy taxes) and final performance (here productivity), with environmental regulatory stringency affecting productivity either directly or through its effect on innovation. To deal with possible lags in the adaptation to new regulatory conditions and to avoid issues of reverse causality, our indicators of energy tax intensity (as well as all our control variables) are included in the regressions with a lag of one year[2].

We implement our empirical model in two steps. In a first step, we investigate separately the direct links between the stringency of environmental regulation (either within-sector, upstream and downstream environmental regulation) and the various measures of performance (innovation and productivity). In a second step, we jointly assess the effect of the stringency of environmental regulation on productivity by decomposing the overall effect in a direct effect and an indirect (mediated) effect transmitted by innovation.

3.1 Direct links between environmental regulations and competitiveness

We estimate a knowledge production function (path (1) in Figure 1), separately from a productivity equation (path (2) in Figure 1). In a second step, we investigate the extent to which innovation acts as mediator when assessing the overall effect of environmental regulatory stringency on productivity performance.

Several problems can affect panel data regressions. As a matter of fact, residuals could be heteroskedastic, autocorrelated and display cross-sectional dependence. Through specific tests, we found all these problems in our data and therefore we use the estimators proposed by Hoechle (2007), in which standard errors are estimated by means of the Driscoll-Kraay estimator. First, for patents only, we estimate a baseline model without any indicator of environmental stringency, in order to assess the role of our set of control variables. In a second set of specifications, we investigate separately the effect of within-sector, upstream and downstream environmental stringency. Then, we put all the three measures in the same regression equation. Finally, we add, respectively, an interaction term between within-sector environmental regulatory stringency and upstream and downstream environmental regulatory stringency to investigate whether they act as substitutes or complements.

3.1.1 Knowledge production function

Path (1) in Figure 1 investigates the induced-innovation effect of environmental regulatory stringency. That is we consider the effect of environmental

[2]Reverse causality could arise because innovation, by (possibly) reducing energy requirements, may help reducing contemporaneous expenditure in energy taxes. However, current innovation output has no effect on past energy intensity.

regulatory stringency on patents as indicated by the weak PH. We investigate this effect in the general framework of a knowledge production function (Griliches, 1990), with the logarithm of total patents as dependent variable[3]. It is to be noted that we use only a measure of aggregate patents rather than 'green' patents as our aim is to test the impact of regulation on overall innovation effort, following the approach of Jaffe and Palmer (1997).

In principle, it would be interesting to investigate the extent to which regulation affects specific kinds of technologies, especially the ones more strictly linked to improvement of energy efficiency or alternative ways of generating energy. The first difficulty is to disentangle with sufficient precision those specific technologies that are more likely to be influenced by more expensive energy input due to taxes. Energy efficiency is a very general and broad concept which could be pursued by a wide variety of technological innovations. Moreover, the response to more expensive energy inputs could go beyond simple improvements of energy efficiency, with more radical changes in processes and products[4]. To our knowledge, the only work on European countries which estimates the effect of environmental regulatory stringency (more specifically, what they define endogenous regulatory stringency) on environmental patents with a sectoral perspective is the work by Ghisetti and Quatraro (2013)[5]. They use actual patents by sector and region by aggregating firm-level data (ORBIS database) for Italy, then identifying environmental patents based on IPC classes. The main limitation of that kind of approach in our context, however, is the limited coverage of patents matched by using firm-level data such as the ORBIS database. The possible alternative, that is assigning environmental patents to sectors based on 'static' IPC-Nace concordances (as we do in this work) together with identifying environmental patents based on a static list of IPC classes, is likely to generate some distorsions due to the fact that there is an *a priori* link of specific technologies (e.g. environmental technologies identified through IPC classes) to specific sectors (through the static IPC-Nace concordance).

[3]Many empirical analyses treat patents as a count variable. However, when assigning patents to sectors or countries, the issue of international (or inter-sectoral) co-patenting patterns implies fractional assignment of patents to countries or sectors. This results in non-integer values for patent counts. Moreover, our measure of total patents is always non-zero for all observations, thus allowing to take the logarithm without losing any observation.

[4]Organizational changes are also likely to arise due to more stringent environmental regulation. However, patent data are not the adequate tool to capture these kinds of responses.

[5]Such kind of studies are more common for the US (e.g. Brunnermeier and Cohen (2003) and Carrion-Flores and Innes (2010)) for which data on actual patents by sector are more easily available.

The novelty of our approach is that of testing the effect on the dependent variable by also considering the stringency of the downstream and upstream sector through the use of input-output matrices. If patents mainly cover 'product' innovations, we should expect an increasing 'demand' for better technologies by downstream sectors towards their suppliers of technologies as a consequence of more stringent environmental regulations. Secondly, if the upstream sector is affected by increasing costs due to regulation and part of these costs result in higher prices[6], its buyers (downstream sectors) are induced to innovate in order to deal with the new relative prices of intermediate goods (induced innovation). We also consider the case in which the effects of downstream and upstream regulation can interact with 'within-sector' regulation to generate an impact on innovation. As inputs in the knowledge production function we include investment in research and development (logarithm of R&D expenditure), the stock of available knowledge (logarithm of patent stock), the quality of human capital (proxied by the logarithm of average wage) as well as the logarithm of total employees to control for the scale of the sector. Moreover, we include year dummies to account, among other things, for changes in the propensity to patent common to all sectors and countries.

3.1.2 Productivity equation

To test the strong version of the PH, we estimate the direct effect of our measures of environmental stringency on productivity, that is the path (2) in Figure 1. In this case environmental regulatory stringency can contribute to increase the economic performance, here measured in terms of TFP (total factor productivity) or labour productivity, because firms have the technological capabilities to offset the costs implied by environmental policy. In this part of the analysis, for example, environmental regulation might stimulate and accelerate organizational changes, with positive productivity effects, and might generate the conditions for the creation of new markets, as suggested by Porter and van der Linde (1995), with positive effects on productivity.

3.2 Mediated effects

The literature on the PH emphasizes the role of induced innovation as a channel to (more than) offset environmental compliance costs. However, with few

[6]The extent to which increasing costs result in higher prices and not in lower margins depends on the structure of the specific market for intermediate goods (e.g. market power, differentiation of products, number of customers, elasticity of demand and supply).

exceptions such as Hamamoto (2006) and Yang et al. (2012), empirical analyses either focus on the induced-innovation effect only (e.g. Johnstone et al. (2012), path (1) in Figure 1) or they investigate the overall effect environmental regulatory stringency on indicators of economic performance such as profits or productivity (e.g. Lanoie et al. (2011)) with no explicit investigation of the mediating effect of innovation. Our approach aims at filling this gap by decomposing the overall effect of our measures of environmental regulatory stringency on productivity between a direct effect and an indirect effect, the last one being transmitted (mediated) by innovation.

[Figure 2 about here]

In addition to the productivity equation (dashed arrows in Figure 2), in which we have our productivity measure as dependent variable ($y_{cs,t}$) and, as regressors, the various measures of environmental regulatory stringency ($X_{cs,t}$) and the mediating variable ($m_{cs,t}$), we also estimate an equation for the mediating variable ($m_{cs,t}$ - here innovation measured by patents) in which we include the baseline controls ($Z_{cs,t}$) already described above and the measures of environmental regulatory stringency ($X_{cs,t}$).

$$
\begin{aligned}
y_{cs,t} &= X'_{cs,t}\gamma + m_{cs,t}\beta + \theta_{cs} + \tau_t + \eta_{cs,t} \\
m_{cs,t} &= X'_{cs,t}\alpha + Z'_{cs,t}\delta + \mu_{cs} + \omega_t + \varepsilon_{cs,t}
\end{aligned}
\tag{1}
$$

In this framework, environmental regulatory stringency influences productivity directly (γ) as well as indirectly through the mediator ($\alpha \times \beta$), with the overall effect given by $\gamma + \alpha \times \beta$. Being the indirect and overall effects non-linear combinations of parameters, they follow a non-normal distributions. For that reason, as suggested by Preacher et al. (2007), we report standard errors computed with bootstrap (500 replications). A common test to assess the presence of mediation is the Sobel test (Preacher and Hayes, 2008). The test could be interpreted in two different alternative ways. First, starting from a simple regression in the form of $y_{cs,t} = X'_{cs,t}\gamma + \theta_{cs} + \tau_t + \eta_{cs,t}$, mediation is relevant if the vector γ experiences a statistically significant change when the mediator $m_{cs,t}$ is added as regressor. A second approach, equivalent but probably easier to interpret, is to test the significance of indirect effects ($\alpha \times \beta$) in equation 1.

This approach allows us to investigate also the path (3) of Figure 1, thus providing a comprehensive picture of the full chain of causality between environmental regulatory stringency and productivity.

4 Data

Our analysis is based on a longitudinal dataset composed by 13 manufacturing sectors[7] for seven European countries[8] and the period 2001-2007. The panel includes 621 observations for a total of 89 sector-country pairs[9].

4.1 Dependent variables

We use two sets of dependent variables to describe the performance of European manufacturing sectors. Innovative output is measured by means of EPO (European Patent Office) patent applications assigned to each sector. Patents have been assigned to manufacturing sectors according to the IPC-Nace concordance table done by Schmoch et al. (2003). As robustness check, we tested our results with the newly released IPC-Nace concordance table, based on text similarity algorithms, prepared by Lybbert and Zolas (2013). The use of patent data, even though affected by some drawbacks such as the fact of being biased towards product innovations, has been considered as one of the best measures of technological innovations as the focus is on outputs rather than inputs (as the case of R&D expenditures).

Performance in terms of productivity is measured by means of a TFP index (EUKLEMS[10]) and, as a robustness check, in terms of labour productivity (value added per employee, from the WIOD[11] database).

[7] Nace rev. 1.1. DA: food products, beverages and tobacco. DB: textiles and textile products. DC: leather and leather products. DD: wood and wood products. DE: pulp, paper and paper products, publishing and printing. DF: coke, refined petroleum products and nuclear fuel. DG: chemicals, chemical products and man-made fibers. DH: rubber and plastic products. DI: other non-metallic mineral products. DJ: basic metals and fabricated metal products. DK: machinery and equipment n.e.c.. DL: electrical and optical equipment. DM: transport equipment. DN: manufacturing n.e.c..

[8] Austria (AT), Belgium (BE), Czech Republic (CZ), Germany (DE), Italy (IT), the Netherlands (NL) and Sweden (SE).

[9] The potential size of the panel was of 637 observations. However, sector DF is missing for the entire period for Austria and Czech Republic and sector DL is missing in 2006 and 2007 for Sweden.

[10] http://www.euklems.net.

[11] World Input Output Database, http://www.wiod.org.

4.2 Independent variables

4.2.1 Environmental regulation: within-sector, upstream and downstream regulation

In the empirical literature environmental regulations are usually proxied by pollution abatement costs (e.g. Shadbegian and Gray (2005)) or the amount of pollutant emissions (e.g. Xing and Kolstad (2002)). Instead, in this paper, our main variable of interest (environmental regulatory stringency) is proxied by energy taxes. Our idea is that the higher the amount of taxes, the tighter is the regulation.

Data on energy taxes are characterized by nice features which make them suitable for our purposes. First, data are available with sectoral breakdown for all economic branches as opposed to environmental protection expenditure, generally unavailable or aggregated for non-manufacturing sectors. Being available with great detail for all sectors allows to build reliable indicators of upstream and downstream measures of stringency. Second, they are a continuous and time-varying measures of environmental regulatory stringency, differently from alternative discrete measures related to the introduction of specific environmental regulations. The use of energy taxes also brings about some serious limitations. First, while the outcome of energy taxes, which is making fossil fuels directly or indirectly more expensive, has important environmental implications, the motivation behind the introduction of energy taxes is often not related to environmental issues. Among other purposes, energy taxes are introduced as a relatively efficient source of tax revenue (due to the inelastic nature of energy demand) or they may act as strategic fiscal tools to improve energy security (relevant for countries with limited natural and mineral resources) or to translate part of the fiscal burden on foreign producers of energy. Second, despite their relevance and pervasiveness, they represent just one among many regulatory instruments for environmental purposes. Finally, in times of volatile energy prices, changes in energy taxes represent a relatively small fraction of the changes in total gross energy prices.

We use three different variables as measures of environmental regulatory stringency: within-sector intensity[12] of energy taxes, upstream average intensity of energy taxes and downstream average intensity of energy taxes. An estimate of the revenue from energy and, more generally, environmental taxes with a sectoral breakdown is provided by Eurostat in the database

[12] Intensity is defined as total sectoral revenues from energy taxes (Eurostat) per unit of value added (WIOD).

'Environmental taxes by economic activity'[13]. Regulation 691/2011 of the European Parliament and of the Council requires Member States to submit to Eurostat information on the revenue from environmentally related taxes by economic activities.

Upstream and downstream energy tax intensities have been computed by weighting the intensity of energy taxes (per unit of value added) of all other production sectors of the economy, including other industrial sectors, agriculture and all service sectors. Weights have been built by using the annual input-output tables of the WIOD database that have the advantage of being available for all years. Being $\mathbf{Z}$ the square input-output matrix of domestic intermediate inputs, $\mathbf{x}$ the column vector of gross domestic output and $\mathbf{i}$ the summation column vector, the weighting matrix for upstream sectors is given by $\mathbf{Z} < \mathbf{Z'i} >^{\mathbf{-1}}$ while the weighting matrix for downstream sectors is given by $\mathbf{Z} < \mathbf{x} >^{\mathbf{-1}}$. What is missing from this weighting approach is regulation 'embodied' in imported intermediate inputs and regulation 'embodied' in the part of export related to intermediate inputs of partner countries. While estimates of inter-sectoral cross-country flows of intermediate inputs is available in WIOD, no comprehensive information on energy taxes (especially with a sectoral breakdown) for many trading partners is currently available.

4.2.2 Controls

We employ specific controls for each category of dependent variables. We use total employment (in terms of headcount, from the WIOD database) as a variable of size of the sector. Innovation input is measured with R&D expenditure (from OECD Anberd). Knowledge stock is measured by means of the stock of EPO patents. The stock is built with the perpetual inventory method starting from 1977 (year in which the European Patent Office has been created), assuming a depreciation rate of 15 percent. In this case, we use patent assigned to sectors by using the IPC-Nace concordance table recently developed by Lybbert and Zolas (2013) instead of the concordance proposed by Schmoch et al. (2003). As a measure of human capital we build an indicator of average wage (compensation to employees - Eurostat - per employee - WIOD). Finally, as a measure of market structure, we use the share of big firms (more than 250 employees) by sector (OECD Structural Business Statistics).

[13]http://epp.eurostat.ec.europa.eu/portal/page/portal/product_details/dataset?p_product_code=ENV_AC_TAXIND

4.3 Descriptive statistics

Table 1 reports average values for some of our relevant variables by country and by sector while Table 2 shows some descriptive statistics for the variables used in the regression analysis. We can note that, in terms of innovation output (number of patents per 1,000 employees), the Netherlands stands out, with more than 4 patents per thousand employees, followed by Germany. Instead, in terms of innovation input (ratio of R&D on added value) the amount is highest for Sweden. With respect to energy taxes, we can recognize that Italy, together with the Czech Republic, is one of the countries with the highest amount of taxes, within-sector as well as in downstream and upstream sectors. Sector DD (wood products) and sector DL (electrical and optical equipment) are those sectors respectively with the lowest and the highest innovation output.

Finally, Figure 3 describes aggregate trends of the intensity (per value added) of energy taxes by country, aggregated for all manufacturing sectors. While the intensity of energy taxes on value added tends to increase in the Czech Republic and Belgium, a decrease is observed for Italy and no specific pattern is visible for other countries.

5 Results

5.1 Direct links between environmental regulations and competitiveness

Before commenting on the results of our econometric exercise, it is worth discussing the extent to which our variables correlate each other. The correlation matrix (Table 3) of our variables of interest[14] shows a quite high value for correlation between upstream and downstream energy tax intensity (about .93), between TFP and labour productivity (about .73), between patents and R&D (about .64), between average wage and patent stock (about .54) and between labour productivity and patent stock (about .51), while all other correlations are smaller than .5. The high correlation between upstream and downstream energy tax intensity is particularly relevant for our analysis, in which we should interpret with particular care the estimates in which the two measures appear together.

In Table 4 we show the first step of our estimation strategy, that is the effect played by environmental taxes on patents. In column 1 we estimate a benchmark model, which includes the most common drivers of innova-

[14]Correlation is computed on the within transformation of the variables.

tion output. Results are in line with expectations: R&D, knowledge stock and human capital (here in terms of average wage), traditional inputs of any knowledge production function, positively and significantly affect patent applications. Once controlling for the input of the knowledge production function, our measure of size of the sector (number of employees) turns out to be insignificant. Finally, patenting is positively related with changes in the presence of big firms in the sector, due to the greater propensity to patent by big firms.

From column 2 onwards we add our main variables of interest one by one[15]. We notice a strong positive effect of within-sector, upstream and downstream stringency, confirming the induced-innovation hypothesis. The classical 'within-sector' inducement (column 2) results in an increase of 2.5 percent in patents in response to an increase of within-sector energy tax intensity by one standard deviation.

The effect of upstream inducement (column 3) is greater in magnitude (increase of 10.7 percent in patents for a one standard deviation increase in upstream energy tax intensity). This evidence suggests the existence of a partial (but relevant) adjustment of the price of intermediate goods due to changes in energy taxes which gives rise to innovations aimed at changing the mix of intermediate inputs in response to the new relative prices of inputs.

Finally, the effect is particularly strong in terms of magnitude for the downstream stringency measure: an increase of downstream energy tax intensity by one standard deviation induces an increase in patents of 13 percent. The relevance of this variable could be driven by the fact that patents are typically covering product innovations which are thus transferred (embodied technical change) to downstream (more regulated) sectors. When putting together all the three measures of energy tax intensity, within-sector and upstream measures disappear both in terms of magnitude of the coefficients and statistical significance, while downstream stringency remains positive and (weakly) significant, suggesting that its effect tends to be the strongest.

In the last two columns we interact each of the upstream and downstream variables with the one measuring the effect of within-sector environmental stringency. We note there is a sort of substitution effect between within-sector and downstream and upstream stringency as drivers of knowledge production, as the sign for the interaction with the downstream tax is negative. This means that holding the 'within-sector' tax constant, the effect of increasing downstream or upstream stringency can more than offset the

[15]Our variables of environmental regulatory stringency have been transformed into Z-scores. Estimated coefficients should be interpreted as percentage change in the dependent variable due to an increase of one standard deviation in the measure of environmental regulatory stringency.

capability of the sector of recovering the investment done to comply with the regulation.

To model the last part of the relationships identified in Figure 1, we directly estimate the effect of environmental taxes on TFP (Table 5) and labour productivity (Table 6). In this way we can directly understand whether the strong version of the PH is confirmed. When investigated separately, all three measures of environmental regulatory stringency positively affect productivity, the effect being greater in magnitude for labour productivity rather than TFP. However, when including all three measures in the same specification, while the effect of within-sector energy tax intensity remains unchanged in sign, magnitude and significance, we observe relevant changes in the effect of downstream and upstream measures of energy tax intensity. The effect of downstream energy tax intensity increases substantially in magnitude while the upstream energy tax intensity turns out to have a negative and significant effect on both TFP and labour productivity. Even though these results should be interpreted with caution due to the strong 'within' correlation between downstream and upstream energy tax intensity[16], they suggest that possible increases in the price of intermediate inputs due to energy taxes could reduce productivity. Finally, interaction terms between within-sector energy tax intensity and downstream and upstream energy tax intensity are insignificant in all cases, suggesting no substitution or complementarity when considering productivity instead of innovation as outcome variable.

5.2 Robustness checks

We carry out some sensitivity analysis to check the robustness of our results. We only include the specification in which all the variables measuring regulations are considered together without interactions. First, we investigate the extent to which results remain stable when we exclude Germany. Indeed, this country, even though not showing the highest amount of patent and R&D intensity is nevertheless the biggest in term of size as shown by the high value of the variable measuring the number of employees. Looking at the first column of Table 9, we see that results are confirmed as downstream energy taxes generate a positive effect on patents. Then, we exclude the two sectors with the highest (DL - electrical and optical equipment) and lowest (DD - wood and wood products) R&D intensity and, finally, sector DF (coke, refined petroleum products and nuclear fuel) which is somewhat an outlier in terms of within-sector energy tax intensity and is very small in

[16]Despite the strong correlation, the VIF (variance inflation factor) is always lower than 5.

terms on value added and number of employees in many countries. We note that, excluding DD, the effect of downstream and upstream energy taxes disappears and only direct effect is positive and significant. This means that excluding a sector which is weak on the input side of the innovation process can reverberate on the effect generated by downstream or upstream taxes. Instead, excluding DF, a sort of outlier sector while preserving the effect of downstream taxes generates a positive effect also on the side of within-sector taxes. This may be due to the fact that higher energy taxes impact not only through input-output relationship but also they impact through a within-sector effect. Instead, excluding the sector which is the highest in term of technological intensity, DL, does not affect the main results. Table 10 for TFP reports results that are in line with those found in the benchmark regressions. The only exception is the sample without sector DF in which only within-sector taxes are positive and significant.

5.3 Mediated effects

Results for the estimates of mediated effects are reported in Tables 7 and 8 for TFP and labour productivity as final outcome variables respectively. In the first line, we report the direct effect of each indicator of energy tax intensity on productivity. In the second line we report the effect of the mediator (patents) on productivity[17]. In the third line we compute the effect of energy taxes on the mediator. In the fourth line we report the indirect effect of energy taxes on productivity (given by the product between the effect of energy taxes on the mediator and the effect of the mediator on productivity) and, finally, in the last line we report the overall effect of energy taxes on productivity (given by the sum of direct and indirect effects). We first note that we can only account for a significant direct and overall effect for the within-sector and downstream taxes. These effects can be decomposed into a direct effect, which implies testing whether taxes affect productivity directly, and an indirect effect implying testing whether taxes affects productivity through patents. The main result we get is that while energy taxes directly affect productivity, patents are not a good mediator. Indeed, we get insignificant results for the coefficient measuring the effect of patents on productivity. This leads us to conclude that patents even though positively affected by energy taxes, as shown by the previous results, do not act as a mediator of the effect observed when investigating the strong version of PH.

[17]This effect is clearly common for all indicators of regulatory stringency.

6 Conclusion

Although different versions of the PH have been analyzed so far, we propose a theoretically similar but empirically different exercise. What we do in this paper is to dig deeper into the PH by analyzing the extent to which both its strong and weak versions are realized for European manufacturing sectors in 7 countries over the period 2001-2007. The main novelty we introduce is that we account for the inducement that each sector may receive from regulations not only in the same sector, but also from regulations of upstream and downstream sectors. This has been made possible by using country- and year-specific input-output data provided by the WIOD database. In particular, we focus on the role played by energy taxes, a measure scarcely used to test the PH. A second novelty we introduce is that we do not only measure the 'direct' effect coming from energy taxes respectively on patents and productivity but we also measure the 'indirect' effects of energy taxes on productivity transmitted by their effect on patents.

The results we get with respect to the first step of the analysis reveal that the strongest effects both on patents and productivity come from downstream taxes. The reason we give is that higher taxes for downstream sectors induce their corresponding upstream sectors to innovate in order to generate new adequate intermediate goods which could improve energy efficiency of the downstream sectors. Upstream sectors act as specialized suppliers of technology, as described in the theoretical model by Heyes and Kapur (2011). These type of taxes are also those that generate a higher effect on productivity. However, when coming to measure the indirect effect generated by taxes through induced innovation, patents are not good mediators for such effect.

Therefore the investigation of other channels of transmissions through which the effect of the strong version of the PH are realized can be an important issue on which further research can concentrate.

References

Alpay, E., S. Buccola, and J. Kerkvliet (2002). Productivity growth and environmental regulation in Mexican and U.S. food manufacturing. *American Journal of Agricultural Economics 84(4)*, 887–901.

Arimura, T., A. Hibiki, and N. Johnstone (2007). An empirical study of environmental R&D: what encourages facilities to be environmentally innovative. In *Environmental Policy and Corporate Behaviour*. Edward Elgar, Cheltenham.

Brunnermeier, S. B. and M. A. Cohen (2003). Determinants of environmental innovation in US manufacturing industries. *Journal of Environmental Economics and Management 45*, 278–293.

Carrion-Flores, C. E. and R. Innes (2010, January). Environmental innovation and environmental performance. *Journal of Environmental Economics and Management 59*(1), 27–42.

Ghisetti, C. and F. Quatraro (2013). Beyond inducement in climate change: Does environmental performance spur environmental technologies? a regional analysis of cross-sectoral differences. *Ecological Economics* (Forthcoming).

Gollop, F. M. and M. J. Roberts (1983, August). Environmental regulations and productivity growth: The case of fossil-fueled electric power generation. *Journal of Political Economy 91*(4), 654–74.

Gray, W. B. and R. J. Shadbegian (1998). Environmental regulation, investment timing, and technology choice. *Journal of Industrial Economics 46*(2), 235–56.

Gray, W. B. and R. J. Shadbegian (2003). Plant vintage, technology, and environmental regulation. *Journal of Environmental Economics and Management 46*(3), 384–402.

Greaker, M. (2006). Spillovers in the development of new pollution abatement technology: A new look at the Porter-hypothesis. *Journal of Environmental Economics and Management 52*(1), 411–420.

Greaker, M. and K. E. Rosendahl (2008). Environmental policy with upstream pollution abatement technology firms. *Journal of Environmental Economics and Management 56*(3), 246–259.

Griliches, Z. (1990). Patent statistics as economic indicators: A survey. *Journal of Economic Literature 28*(4), 1661–1707.

Hamamoto, M. (2006). Environmental regulation and the productivity of Japanese manufacturing industries. *Resource and Energy Economics 28*, 299–312.

Heyes, A. and S. Kapur (2011). Regulatory attitudes and environmental innovation in a model combining internal and external R&D. *Journal of Environmental Economics and Management 61*(3), 327–340.

Hoechle, D. (2007). Robust standard errors for panel regressions with cross-sectional dependence. *The Stata Journal 7*, 281–312.

Jaffe, A. and K. Palmer (1997). Environmental regulation and innovation: a panel data study. *Review of Economics and Statistics 79 (4)*, 610–619.

Jaffe, A. B. and R. N. Stavins (1995, November). Dynamic incentives of environmental regulations: The effects of alternative policy instruments on technology diffusion. *Journal of Environmental Economics and Management 29*(3), S43–S63.

Johnstone, N., I. Hai, J. Poirier, M. Hemar, and C. Michel (2012, June). Environmental policy stringency and technological innovation: evidence from survey data and patent counts. *Applied Economics 44*(17), 2157–2170.

Kneller, R. and E. Manderson (2012). Environmental regulations and innovation activity in UK manufacturing industries. *Resource and Energy Economics 34*(2), 211–235.

Lanoie, P., J. Laurent-Lucchetti, N. Johnstone, and S. Ambec (2011). Environmental policy, innovation and performance: New insights on the Porter Hypothesis. *Journal of Economics & Management Strategy 20*(3), 803–842.

Lanoie, P., M. Patry, and r. Lajeunesse (2008). Environmental regulation and productivity: New findings on the Porter Hypothesis. *Journal of Productivity Analysis 30*, 121–128.

Leiter, A. M., A. Parolini, and H. Winner (2011). Environmental regulation and investment: Evidence from European industry data. *Ecological Economics 70*(4), 759–770.

Lybbert, T. J. and N. J. Zolas (2013). Getting patents and economic data to speak to each other: An 'algorithmic links with probabilities' approach for joint analyses of patenting and economic activity. *Research Policy* (In press).

Popp, D. (2006). International innovation and diffusion of air pollution control technologies: the effects of NOX and SO2 regulation in the US, Japan, and Germany. *Journal of Environmental Economics and Management 51*(1), 46–71.

Porter, M. and C. van der Linde (1995). Toward a new conception of the environment-scompetitiveness relationship. *Journal of Economic Perspectives 9 (4)*, 97–118.

Preacher, K. J. and A. F. Hayes (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods 40*, 879–891.

Preacher, K. J., D. D. Rucker, and A. F. Hayes (2007). Addressing moderated mediation hypotheses: Theory, methods, and prescriptions. *Multivariate Behavioral Research 42*, 185–227.

Schmoch, U., F. Laville, P. Patel, and R. Frietsch (2003). Linking technology areas to industrial sectors. Final report to the european commission, DG Reasearch European Commission.

Shadbegian, R. J. and W. B. Gray (2005, August). Pollution abatement expenditures and plant-level productivity: A production function approach. *Ecological Economics 54*(2-3), 196–208.

Xing, Y. and C. Kolstad (2002, January). Do lax environmental regulations attract foreign investment? *Environmental & Resource Economics 21*(1), 1–22.

Yang, C.-H., Y.-H. Tseng, and C.-P. Chen (2012). Environmental regulations, induced R&D, and productivity: Evidence from Taiwan's manufacturing industries. *Resource and Energy Economics 34*(4), 514–532.

Figure 1: Model

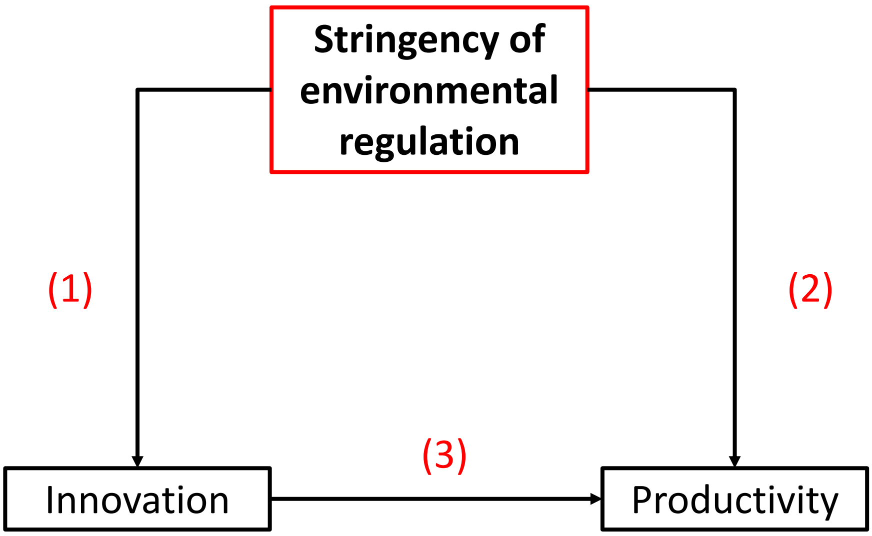

Table 1: Averages by country and sector

Country	Patent/L	R&D/VA	Patent stock	Average wage	Empl	Share big firms	Within tax/VA	Downstr tax/VA	Upstr tax/VA
AT	2.4053	0.0650	4.6280	33.0419	51.2403	0.0271	0.0103	1.9399	3.5488
BE	2.3581	0.0525	9.2958	49.3202	46.3619	0.0189	0.0030	1.3918	2.3520
CZ	0.1042	0.0649	0.1415	8.1017	102.1897	0.0181	0.0359	5.8215	8.3477
DE	3.5585	0.0604	18.8131	44.7299	575.2088	0.0401	0.0145	3.3210	6.1002
IT	1.2856	0.0400	3.7547	28.6343	324.0879	0.0079	0.0365	6.5366	11.5396
NL	4.0799	0.0437	17.7326	44.7287	71.7889	0.0284	0.0133	1.2591	2.5115
SE	2.8996	0.0928	20.1775	30.2996	56.3944	0.0150	0.0088	3.6295	6.4597
Sector	**Patent/L**	**R&D/VA**	**Patent stock**	**Average wage**	**Empl**	**Share big firms**	**Within tax/VA**	**Downstr tax/VA**	**Upstr tax/VA**
DA	0.4751	0.0131	2.8391	26.6967	248.9415	0.0118	0.0123	2.4172	7.0198
DB_DC	0.4465	0.0200	9.9886	21.4459	162.0349	0.0065	0.0121	1.7386	4.0971
DD	0.0997	0.0049	2.0678	23.3338	60.3135	0.0023	0.0133	5.7680	7.7322
DE	0.3398	0.0067	3.1322	29.1842	167.7066	0.0089	0.0126	4.1389	5.9953
DF	7.9315	0.1190	94.4870	143.3327	12.4214	0.0907	0.0666	5.9476	11.5342
DG	7.6301	0.1337	15.3401	34.2604	133.3655	0.0553	0.0467	2.2353	3.1007
DH	1.1105	0.0343	2.5963	26.9565	110.9178	0.0222	0.0076	4.5342	5.7336
DI	1.0942	0.0219	5.4756	29.6523	96.5670	0.0122	0.0267	7.1420	9.3555
DJ	0.7446	0.0202	2.3913	28.7602	343.4830	0.0079	0.0132	3.5897	4.3547
DK	2.4376	0.0904	6.1477	33.3151	298.7093	0.0189	0.0070	1.8154	5.1381
DL	7.2111	0.1412	11.3223	26.0926	279.7052	0.0132	0.0050	2.1347	3.6726
DM	2.9081	0.1757	3.1861	31.4076	234.5207	0.0534	0.0058	1.2830	3.0478
DN	0.6530	0.0153	5.4168	24.0553	121.2778	0.0049	0.0107	2.1696	6.5823
Total	2.4083	0.0597	10.8047	34.4401	177.9307	0.0222	0.0174	3.4030	5.8326

Table 2: Descriptive statistics

Variable	Mean	Median	SD	Min	Max
log(patent)	4.165	4.079	2.112	-3.244	8.885
TFP index	1.186	1.115	0.410	0.222	6.941
log(VA/L)	3.845	3.969	0.698	1.547	6.060
log(R&D)	4.647	4.588	1.999	-1.897	9.744
log(patent stock)	5.607	5.835	1.879	0.041	9.492
log(average wage)	3.300	3.406	0.660	1.312	5.764
log(L)	4.450	4.380	1.214	0.993	7.026
Share big firms	0.022	0.012	0.035	0.000	0.286
Within energy tax	0.017	0.009	0.041	0.000	0.461
Downstr energy tax	3.403	2.520	3.050	0.147	18.309
Upstr energy tax	5.833	4.700	4.497	0.340	33.555

Table 3: Correlation matrix

		(1)	(2)	(3)	(4)	(5)	(6)	(6)	(7)	(8)	(9)	(10)
log(patent)	(1)	1	0.2624*	0.3957*	0.0308	0.1801*	0.1234*	0.1937*	0.6373*	0.4676*	-0.2188*	-0.0387
TFP index	(2)		1	0.7258*	0.0635	0.0204	-0.0150	0.0818	0.3355*	-0.1293*	-0.0629	-0.0403
log(VA/L)	(3)			1	0.2669*	0.0346	0.0236	0.1675*	0.5062*	-0.0761	-0.2281*	-0.0768
Within energy tax	(4)				1	0.2109*	0.2787*	0.2192*	0.0283	-0.3538*	-0.0575	-0.0374
Downstr energy tax	(5)					1	0.9157*	0.2457*	0.1221*	0.0064	0.0953	0.0715
Upstr energy tax	(6)						1	0.1923*	0.0485	-0.0321	0.0537	0.0964
log(R&D)	(6)							1	0.2382*	0.0692	0.0747	0.0823
log(patent stock)	(7)								1	0.5396*	-0.2342*	-0.1012
log(average wage)	(8)									1	-0.2430*	-0.0559
log(L)	(9)										1	0.0451
Share big firms	(10)											1

For each variable we subtracted its sector-country mean (within transformation). * p¡.01

Figure 2: Mediation

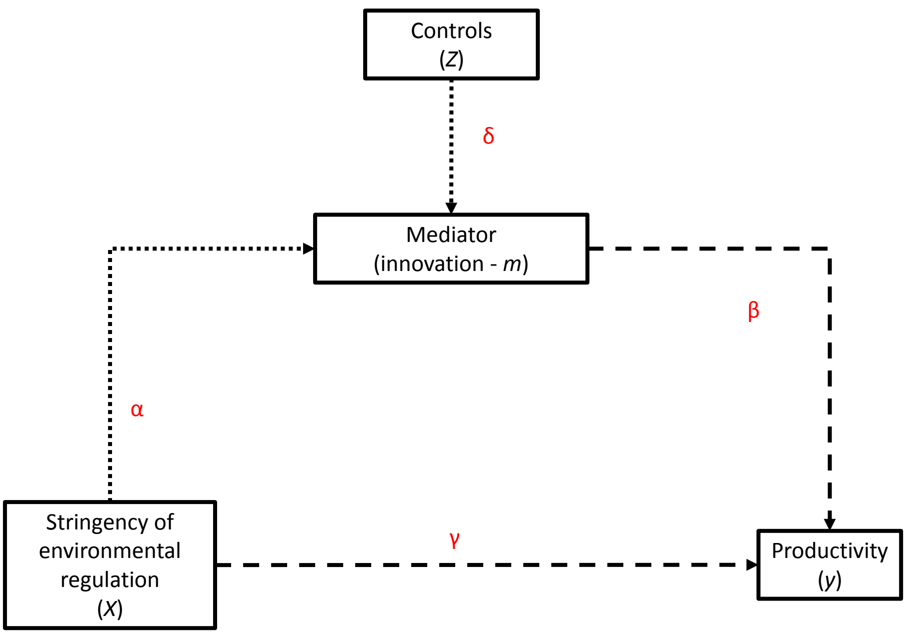

Figure 3: Energy tax / VA

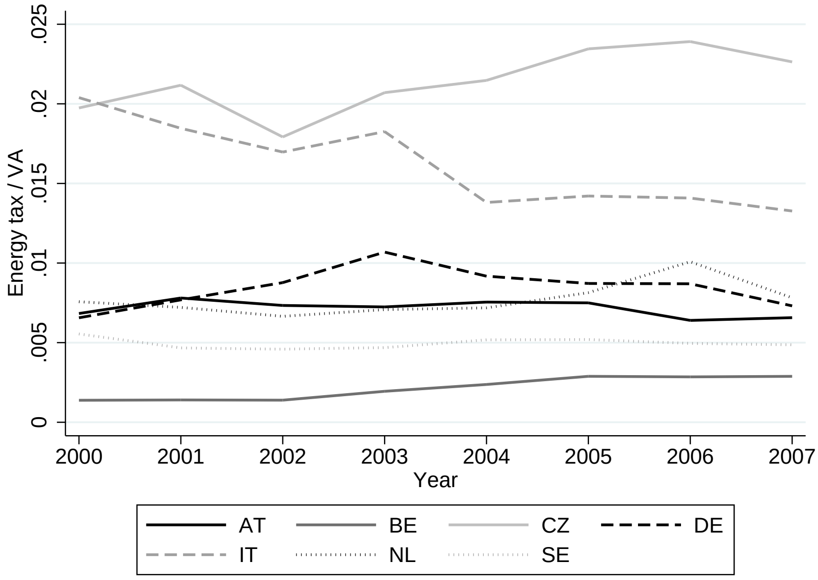

Table 4: Knowledge production function

Dep: log(patent)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
log(R&D)	0.0370**	0.0278*	0.0232	0.0178	0.0121	0.0233	0.0195
	(0.0165)	(0.0166)	(0.0147)	(0.0156)	(0.0179)	(0.0157)	(0.0154)
log(patent stock)	0.404***	0.385***	0.349***	0.322**	0.310**	0.308***	0.277**
	(0.134)	(0.126)	(0.122)	(0.125)	(0.126)	(0.114)	(0.115)
log(average wage)	0.153*	0.200**	0.147**	0.143*	0.175**	0.181**	0.189**
	(0.0872)	(0.0940)	(0.0725)	(0.0748)	(0.0857)	(0.0804)	(0.0834)
log(L)	0.0119	0.0434	0.0582	0.0466	0.0580	0.0986*	0.0990*
	(0.0393)	(0.0353)	(0.0574)	(0.0557)	(0.0509)	(0.0589)	(0.0564)
Share big firms	0.253**	0.295**	0.179*	0.208*	0.256***	0.192*	0.220*
	(0.114)	(0.117)	(0.104)	(0.112)	(0.0872)	(0.101)	(0.113)
Within energy tax		0.0250**			0.0171	0.0879***	0.108***
		(0.0106)			(0.0105)	(0.0126)	(0.0135)
Upstream energy tax			0.107***		-0.0460	0.115***	
			(0.0239)		(0.0751)	(0.0312)	
Downstream energy tax				0.131***	0.168*		0.149***
				(0.0264)	(0.0845)		(0.0370)
Within energy tax × Upstream energy tax						-0.0172***	
						(0.00410)	
Within energy tax × Downstream energy tax							-0.0278***
							(0.00532)
N	621	621	621	621	621	621	621
R sq within	0.467	0.471	0.483	0.489	0.490	0.490	0.499
F	2.341	2.322	5.058	4.122	23.03	9.090	12.59

Driscoll-Kraay standard errors in parentheses. * p< 0.1, ** p< 0.05, *** p< 0.01

Table 5: TFP equation

Dep: TFP index	(1)	(2)	(3)	(4)	(5)	(6)
Within energy tax	0.0456***			0.0487***	0.0530***	0.0457**
	(0.0105)			(0.0132)	(0.0176)	(0.0192)
Upstream energy tax		0.0481*		-0.222**	0.0225	
		(0.0248)		(0.107)	(0.0217)	
Downstream energy tax			0.0844***	0.269**		0.0665***
			(0.0273)	(0.106)		(0.0247)
Within energy tax ×					-0.00228	
Upstream energy tax					(0.00364)	
Within energy tax ×						-0.00175
Downstream energy tax						(0.00408)
N	621	621	621	621	621	621
R sq within	0.128	0.123	0.126	0.135	0.128	0.130
F	498.1	281.0	191.8	876.6	515.8	1064.0

Driscoll-Kraay standard errors in parentheses. * p< 0.1, ** p< 0.05, *** p< 0.01

Table 6: Labour productivity equation

Dep: log(VA/L)	(1)	(2)	(3)	(4)	(5)	(6)
Within energy tax	0.0814***			0.0816***	0.0878***	0.0731***
	(0.0167)			(0.0174)	(0.0196)	(0.0224)
Upstream energy tax		0.0746***		-0.115**	0.0266*	
		(0.0246)		(0.0554)	(0.0144)	
Downstream energy tax			0.0870***	0.156***		0.0485***
			(0.0204)	(0.0536)		(0.0127)
Within energy tax ×					-0.00218	
Upstream energy tax					(0.00508)	
Within energy tax ×						0.00118
Downstream energy tax						(0.00480)
N	621	621	621	621	621	621
R sq within	0.419	0.356	0.360	0.429	0.421	0.424
F	8380.5	3105.0	3051.5	9683.1	9169.1	8208.1

Driscoll-Kraay standard errors in parentheses. * p< 0.1, ** p< 0.05, *** p< 0.01

Table 7: TFP equation: effect mediated by patents

	Within tax	Downstr tax	Upstr tax
Direct effect of tax	0.0487	0.275	-0.225
on productivity	(0.0127)***	(0.141)*	(0.157)
	[0.0196]**	[0.171]	[0.190]
Effect of patents	-0.0207	-0.0207	-0.0207
on productivity	(0.103)	(0.103)	(0.103)
	[0.131]	[0.131]	[0.131]
Effect of tax on	0.0228	0.131	-0.0498
patents	(0.0134)*	(0.0832)	(0.0713)
	[0.0210]	[0.105]	[0.0882]
Indirect effect of tax	-0.000471	-0.00271	0.00103
on productivity	(0.00234)	(0.0137)	(0.00546)
	[0.00436]	[0.0211]	[0.0127]
Overall (direct+indirect)	0.0483	0.273	-0.224
effect of tax	(0.0129)***	(0.138)**	(0.156)
	[0.0196]**	[0.168]	[0.190]

Sector-country and year dummies included.
S.E. computed with the Delta method in round brackets.
Bootstrap S.E. (500 repetitions) in square brackets.
* p< 0.1, ** p< 0.05, *** p< 0.01

Table 8: Labour productivity (VA/L) equation: effect mediated by patents

	Within tax	Downstr tax	Upstr tax
Direct effect of tax	0.0815	0.141	-0.108
on productivity	(0.0146)***	(0.0752)*	(0.0888)
	[0.0220]***	[0.0894]	[0.106]
Effect of patents	0.0459	0.0459	0.0459
on productivity	(0.0371)	(0.0371)	(0.0371)
	[0.0461]	[0.0461]	[0.0461]
Effect of tax on	0.0228	0.131	-0.0498
patents	(0.0134)*	(0.0832)	(0.0713)
	[0.0210]	[0.105]	[0.0882]
Indirect effect of tax	0.00104	0.00601	-0.00229
on productivity	(0.00108)	(0.00584)	(0.00350)
	[0.00176]	[0.00871]	[0.00607]
Overall (direct+indirect)	0.0826	0.147	-0.111
effect of tax	(0.0145)***	(0.0744)**	(0.0889)
	[0.0220]***	[0.0894]*	[0.107]

Sector-country and year dummies included.
S.E. computed with the Delta method in round brackets.
Bootstrap S.E. (500 repetitions) in square brackets.
* p< 0.1, ** p< 0.05, *** p< 0.01

Table 9: Knowledge production function (excluding Germany or specific sectors)

Dep: log(patent)	No GER	No DD	No DL	No DF
log(R&D)	0.0133	0.0262***	-0.00315	0.0249
	(0.0196)	(0.00871)	(0.0324)	(0.0227)
log(patent stock)	0.294**	0.233	0.330**	0.238**
	(0.127)	(0.155)	(0.137)	(0.111)
log(average wage)	0.171*	0.212***	0.158*	0.381***
	(0.0897)	(0.0722)	(0.0840)	(0.142)
log(L)	0.0640	0.144***	-0.0524	-0.00998
	(0.0564)	(0.0344)	(0.0595)	(0.0680)
Share big firms	0.323	0.278***	0.259***	3.972**
	(0.333)	(0.0919)	(0.0843)	(1.687)
Within energy tax	0.0157	0.0231**	0.0167	0.0552***
	(0.0103)	(0.0106)	(0.0112)	(0.0184)
Upstream energy tax	-0.0197	0.00340	-0.0545	-0.00569
	(0.0724)	(0.0388)	(0.0815)	(0.0816)
Downstream energy tax	0.149*	0.0827	0.184*	0.155*
	(0.0783)	(0.0500)	(0.0941)	(0.0878)
N	530	572	574	586
R sq within	0.492	0.547	0.508	0.514
F	28.34	101.3	24.30	18.49

Driscoll-Kraay standard errors in parentheses.
* p< 0.1, ** p< 0.05, *** p< 0.01

Table 10: TFP equation (excluding Germany or specific sectors)

Dep: TFP index	No GER	No DD	No DL	No DF
Within energy tax	0.0505***	0.0494***	0.0527***	0.0874***
	(0.0139)	(0.0130)	(0.0144)	(0.0180)
Upstream energy tax	-0.220*	-0.243*	-0.297***	0.116*
	(0.114)	(0.127)	(0.101)	(0.0652)
Downstream energy tax	0.265**	0.310**	0.338***	0.0290
	(0.115)	(0.137)	(0.0924)	(0.0344)
N	530	572	574	586
R sq within	0.137	0.138	0.238	0.144
F	611.5	384.2	8.916	868.1

Driscoll-Kraay standard errors in parentheses.
* p< 0.1, ** p< 0.05, *** p< 0.01

NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI

Fondazione Eni Enrico Mattei Working Paper Series

Our Note di Lavoro are available on the Internet at the following addresses:

http://www.feem.it/getpage.aspx?id=73&sez=Publications&padre=20&tab=1
http://papers.ssrn.com/sol3/JELJOUR_Results.cfm?form_name=journalbrowse&journal_id=266659
http://ideas.repec.org/s/fem/femwpa.html
http://www.econis.eu/LNG=EN/FAM?PPN=505954494
http://ageconsearch.umn.edu/handle/35978
http://www.bepress.com/feem/

NOTE DI LAVORO PUBLISHED IN 2013

CCSD	1.2013	Mikel Bedayo, Ana Mauleon and Vincent Vannetelbosch: Bargaining and Delay in Trading Networks
CCSD	2.2013	Emiliya Lazarova and Dinko Dimitrov: Paths to Stability in Two-sided Matching with Uncertainty
CCSD	3.2013	Luca Di Corato and Natalia Montinari: Flexible Waste Management under Uncertainty
CCSD	4.2013	Sergio Currarini, Elena Fumagalli and Fabrizio Panebianco: Games on Networks: Direct Complements and Indirect Substitutes
ES	5.2013	Mirco Tonin and Michael Vlassopoulos: Social Incentives Matter: Evidence from an Online Real Effort Experiment
CCSD	6.2013	Mare Sarr and Tim Swanson: Corruption and the Curse: The Dictator's Choice
CCSD	7.2013	Michael Hoel and Aart de Zeeuw: Technology Agreements with Heterogeneous Countries
CCSD	8.2013	Robert Pietzcker, Thomas Longden, Wenying Chen, Sha Fu, Elmar Kriegler, Page Kyle and Gunnar Luderer: Long-term Transport Energy Demand and Climate Policy: Alternative Visions on Transport Decarbonization in Energy Economy Models
CCSD	9.2013	Walid Oueslati: Short and Long-term Effects of Environmental Tax Reform
CCSD	10.2013	Lorenza Campagnolo, Carlo Carraro, Marinella Davide, Fabio Eboli, Elisa Lanzi and Ramiro Parrado: Can Climate Policy Enhance Sustainability?
CCSD	11.2013	William A. Brock, Anastasios Xepapadeas and Athanasios N. Yannacopoulos: Robust Control of a Spatially Distributed Commercial Fishery
ERM	12.2013	Simone Tagliapietra: Towards a New Eastern Mediterranean Energy Corridor? Natural Gas Developments Between Market Opportunities and Geopolitical Risks
CCSD	13.2013	Alice Favero and Emanuele Massetti: Trade of Woody Biomass for Electricity Generation under Climate Mitigation Policy
CCSD	14.2013	Alexandros Maziotis, David S. Saal and Emmanuel Thanassoulis: A Methodology to Propose the X-Factor in the Regulated English and Welsh Water And Sewerage Companies
CCSD	15.2013	Alexandros Maziotis, David S. Saal and Emmanuel Thanassoulis: Profit, Productivity, Price and Quality Performance Changes in the English and Welsh Water and Sewerage Companies
CCSD	16.2013	Caterina Cruciani, Silvio Giove, Mehmet Pinar and Matteo Sostero: Constructing the FEEM Sustainability Index: A Choquet-integral Application
CCSD	17.2013	Ling Tang, Qin Bao, ZhongXiang Zhang and Shouyang Wang: Carbon-based Border Tax Adjustments and China's International Trade: Analysis based on a Dynamic Computable General Equilibrium Model
CCSD	18.2013	Giulia Fiorese, Michela Catenacci, Valentina Bosetti and Elena Verdolini: The Power of Biomass: Experts Disclose the Potential for Success of Bioenergy Technologies
CCSD	19.2013	Charles F. Mason: Uranium and Nuclear Power: The Role of Exploration Information in Framing Public Policy
ES	20.2013	Nuno Carlos Leitão: The Impact of Immigration on Portuguese Intra-Industry Trade
CCSD	21.2013	Thierry Bréchet and Henry Tulkens: Climate Policies: a Burden or a Gain?
ERM	22.2013	Andrea Bastianin, Marzio Galeotti and Matteo Manera: Biofuels and Food Prices: Searching for the Causal Link
ERM	23.2013	Andrea Bastianin, Marzio Galeotti and Matteo Manera: Food versus Fuel: Causality and Predictability in Distribution
ERM	24.2013	Anna Alberini, Andrea Bigano and Marco Boeri: Looking for Free-riding: Energy Efficiency Incentives and Italian Homeowners
CCSD	25.2013	Shoibal Chakravarty and Massimo Tavoni: Energy Poverty Alleviation and Climate Change Mitigation: Is There a Trade off?
ERM	26.2013	Manfred Hafner and Simone Tagliapietra: East Africa: The Next Game-Changer for the Global Gas Markets?
CCSD	27.2013	Li Ping, Yang Danhui, Li Pengfei, Ye Zhenyu and Deng Zhou: A Study on Industrial Green Transformation in China
CCSD	28.2013	Francesco Bosello, Lorenza Campagnolo, Carlo Carraro, Fabio Eboli, Ramiro Parrado and Elisa Portale: Macroeconomic Impacts of the EU 30% GHG Mitigation Target
CCSD	29.2013	Stéphane Hallegatte: An Exploration of the Link Between Development, Economic Growth, and Natural Risk
CCSD	30.2013	Klarizze Anne Martin Puzon: Cost-Reducing R&D in the Presence of an Appropriation Alternative: An Application to the Natural Resource Curse
CCSD	31.2013	Johannes Emmerling and Massimo Tavoni: Geoengineering and Abatement: A 'flat' Relationship under Uncertainty

ERM	32.2013	Marc Joëts: Heterogeneous Beliefs, Regret, and Uncertainty: The Role of Speculation in Energy Price Dynamics
ES	33.2013	Carlo Altomonte and Armando Rungi: Business Groups as Hierarchies of Firms: Determinants of Vertical Integration and Performance
CCSD	34.2013	Joëlle Noailly and Roger Smeets: Directing Technical Change from Fossil-Fuel to Renewable Energy Innovation: An Empirical Application Using Firm-Level Patent Data
CCSD	35.2013	Francesco Bosello, Lorenza Campagnolo and Fabio Eboli: Climate Change and Adaptation: The Case of Nigerian Agriculture
CCSD	36.2013	Andries Richter, Daan van Soest and Johan Grasman: Contagious Cooperation, Temptation, and Ecosystem Collapse
CCSD	37.2013	Alice Favero and Robert Mendelsohn: Evaluating the Global Role of Woody Biomass as a Mitigation Strategy
CCSD	38.2013	Enrica De Cian, Michael Schymura, Elena Verdolini and Sebastian Voigt: Energy Intensity Developments in 40 Major Economies: Structural Change or Technology Improvement?
ES	39.2013	Nuno Carlos Leitão, Bogdan Dima and Dima (Cristea) Stefana: Marginal Intra-industry Trade and Adjustment Costs in Labour Market
CCSD	40.2013	Stergios Athanassoglou: Robust Multidimensional Welfare Comparisons: One Vector of Weights, One Vote
CCSD	41.2013	Vasiliki Manousi and Anastasios Xepapadeas: Mitigation and Solar Radiation Management in Climate Change Policies
CCSD	42.2013	Y. Hossein Farzin and Ronald Wendner: Saving Rate Dynamics in the Neoclassical Growth Model – Hyperbolic Discounting and Observational Equivalence
CCSD	43.2013	Valentina Bosetti and Elena Verdolini: Clean and Dirty International Technology Diffusion
CCSD	44.2013	Grazia Cecere, Susanna Mancinelli and Massimiliano Mazzanti: Waste Prevention and Social Preferences: The Role of Intrinsic and Extrinsic Motivations
ERM	45.2013	Matteo Manera, Marcella Nicolini and Ilaria Vignati: Futures Price Volatility in Commodities Markets: The Role of Short Term vs Long Term Speculation
ERM	46.2013	Lion Hirth and Inka Ziegenhagen: Control Power and Variable Renewables A Glimpse at German Data
CCSD	47.2013	Sergio Currarini and Francesco Feri: Information Sharing Networks in Linear Quadratic Games
CCSD	48.2013	Jobst Heitzig: Bottom-Up Strategic Linking of Carbon Markets: Which Climate Coalitions Would Farsighted Players Form?
CCSD	49.2013	Peter Coles and Ran Shorrer: Optimal Truncation in Matching Markets
CCSD	50.2013	Heinrich H. Nax, Bary S. R. Pradelski and H. Peyton Young: The Evolution of Core Stability in Decentralized Matching Markets
CCSD	51.2013	Manuel Förster, Michel Grabisch and Agnieszka Rusinowsk: Anonymous Social Influence
CCSD	52.2013	Nizar Allouch: The Cost of Segregation in Social Networks
ES	53.2013	Fulvio Fontini, Katrin Millock and Michele Moretto: Investments in Quality, Collective Reputation and Information Acquisition
ES	54.2013	Roberta Distante, Ivan Petrella and Emiliano Santoro: Asymmetry Reversals and the Business Cycle
CCSD	55.2013	Thomas Michielsen: Environmental Catastrophes under Time-Inconsistent Preferences
ERM	56.2013	Arjan Ruijs and Herman Vollebergh: Lessons from 15 Years of Experience with the Dutch Tax Allowance for Energy Investments for Firms
ES	57.2013	Luciano Mauro and Francesco Pigliaru: Decentralization, Social Capital and Regional Convergence
CCSD	58.2013	Alexandros Maziotis, Elisa Calliari and Jaroslav Mysiak: Robust Institutions for Sustainable Water Markets: A Survey of the Literature and the Way Forward
CCSD	59.2013	Enrica De Cian, Fabio Sferra and Massimo Tavoni: The Influence of Economic Growth, Population, and Fossil Fuel Scarcity on Energy Investments
CCSD	60.2013	Fabio Sferra and Massimo Tavoni: Endogenous Participation in a Partial Climate Agreement with Open Entry: A Numerical Assessment
ES	61.2013	Daniel Atzori: The Political Economy of Oil and the Crisis of the Arab State System
ERM	62.2013	Julien Chevallier and Benoît Sévi: A Fear Index to Predict Oil Futures Returns
CCSD	63.2013	Dominik Karos: Bargaining and Power
CCSD	64.2013	Carlo Fezzi, Ian J. Bateman, and Silvia Ferrini: Estimating the Value of Travel Time to Recreational Sites Using Revealed Preferences
ES	65.2013	Luca Di Corato, Michele Moretto and Sergio Vergalli: Long-run Investment under Uncertain Demand
ES	66.2013	Michele Moretto, Paolo Panteghini and Sergio Vergalli: Tax Competition, Investment Irreversibility and the Provision of Public Goods
CCSD	67.2013	Dennis Guignet and Anna Alberini: Can Property Values Capture Changes in Environmental Health Risks? Evidence from a Stated Preference Study in Italy and the UK
ES	68.2013	William Brock, Anastasios Xepapadeas and Athanasios Yannacopoulos: Adjustment Costs and Long Run Spatial Agglomerations
ES	69.2013	Sasan Bakhtiari, Antonio Minniti and Alireza Naghavi: Multiproduct Multinationals and the Quality of Innovation
CCSD	70.2013	Rafael González-Val and Fernando Pueyo: Trade Liberalisation and Global-scale Forest Transition
CCSD	71.2013	Elena Claire Ricci: Smart-Grids and Climate Change. Consumer adoption of smart energy behaviour: a system dynamics approach to evaluate the mitigation potential
CCSD	72.2013	Valentina Bosetti and Marco Maffezzoli: Taxing Carbon under Market Incompleteness
CCSD	73.2013	Francesco Silvestri, Stefano Ghinoi and Vincenzo Barone: Nautical Tourism, Carrying Capacity and Environmental Externality in the Lagoon of Marano and Grado

CCSD 74.2013 Herman R.J. Vollebergh and Edwin van der Werf: The Role of Standards in Eco-innovation: Lessons for Policymakers
ES 75.2013 Gérard Mondello: Ambiguous Beliefs on Damages and Civil Liability Theories
CCSD 76.2013 Roberto Antonietti and Alberto Marzucchi: Green Investment Strategies and Export Performance: A Firm-level Investigation
CCSD 77.2013 A.K.S. Chand, Sergio Currarini and Giovanni Ursino: Cheap Talk with Correlated Signals
CCSD 78.2013 Ebru A. Gencer: An Overview of Urban Vulnerability to Natural Disasters and Climate Change in Central America & the Caribbean Region
CCSD 79.2013 Libo Wu, Changhe Li, Haoqi Qian and ZhongXiang Zhang: Understanding the Consumption Behaviors on Electric Vehicles in China - A Stated Preference Analysis
ES 80.2013 Andries Richter and Johan Grasman: The Transmission of Sustainable Harvesting Norms When Agents Are Conditionally Cooperative
CCSD 81.2013 Jonathan Colmer: Climate Variability, Child Labour and Schooling: Evidence on the Intensive and Extensive Margin
ERM 82.2013 Anna Alberini, Will Gans and Charles Towe: Free Riding, Upsizing, and Energy Efficiency Incentives in Maryland Homes
CCSD 83.2013 Inge van den Bijgaart, Reyer Gerlagh, Luuk Korsten and Matti Liski: A Simple Formula for the Social Cost of Carbon
CCSD 84.2013 Elena Claire Ricci: An Integrated Assessment of Super & Smart Grids
CCSD 85.2013 Laura Diaz Anadon, Gregory Nemet and Elena Verdolini: The Future Costs of Nuclear Power Using Multiple Expert Elicitations: Effects of RD&D and Elicitation Design
CCSD 86.2013 Carlo Carraro, Massimo Tavoni, Thomas Longden and Giacomo Marangoni: The Optimal Energy Mix in Power Generation and the Contribution from Natural Gas in Reducing Carbon Emissions to 2030 and Beyond
ES 87.2013 Ho Fai Chan, Bruno S. Frey, Jana Gallus and Benno Torgler: External Influence as an Indicator of Scholarly Importance
CCSD 88.2013 Marianna Gilli, Susanna Mancinelli and Massimiliano Mazzanti: Innovation Complementarity and Environmental Productivity Effects: Reality or Delusion? Evidence from the EU
CCSD 89.2013 Adrien Vogt-Schilb and Stéphane Hallegatte: Marginal Abatement Cost Curves and the Optimal Timing of Mitigation Measures
ERM 90.2013 Lion Hirth: The Optimal Share of Variable Renewables. How the Variability of Wind and Solar Power Affects their Welfare-optimal Deployment
CCSD 91.2013 Massimiliano Mazzanti and Antonio Musolesi: Nonlinearity, Heterogeneity and Unobserved Effects in the CO2-income Relation for Advanced Countries
CCSD 92.2013 ZhongXiang Zhang: Energy and Environmental Issues and Policy in China
CCSD 93.2013 Giacomo Marangoni and Massimo Tavoni: The Clean Energy R&D Strategy for 2°C
CCSD 94.2013 Carlo Fezzi and Ian Bateman: The Impact of Climate Change on Agriculture: Nonlinear Effects and Aggregation Bias in Ricardian Models of Farm Land Values
CCSD 95.2013 Paolo D. Farah and Riccardo Tremolada: A Comparison Between Shale Gas in China and Unconventional Fuel Development in the United States: Health, Water and Environmental Risks
CCSD 96.2013 Florens Flues, Dirk Rübbelke and Stefan Vögele: Energy Efficiency and Industrial Output: The Case of the Iron and Steel Industry
CCSD 97.2013 Gregor Schwerhoff: Leadership and International Climate Cooperation
CCSD 98.2013 Francisco Alvarez and Francisco J. André: Auctioning vs. Grandfathering in Cap-and-Trade Systems with Market Power and Incomplete Information
CCSD 99.2013 Mattia Amadio, Jaroslav Mysiak, Silvano Pecora and Alberto Agnett: Looking Forward from the Past: Assessing the Potential Flood Hazard and Damage in Polesine Region by Revisiting the 1950 Flood Event
CCSD 100.2013 Carlo Orecchia and Ramiro Parrado: A Quantitative Assessment of the Implications of Including non-CO2 Emissions in the European ETS
CCSD 101.2013 Yaella Depietri, Lorenzo Guadagno and Margaretha Breil: Urban Watershed Services For Improved Ecosystem Management and Risk Reduction, Assessment Methods and Policy Instruments: State of the Art
ERM 102.2013 Magali Dauvin: Energy Prices and the Real Exchange Rate of Commodity-Exporting Countries
ERM 103.2013 Chiara Franco and Giovanni Marin: The Effect of Within-Sector, Upstream and Downstream Energy Taxes on Innovation and Productivity