LLEE Working Paper Series

ENVIRONMENTAL REGULATION AND PRODUCTIVITY GROWTH:
MAIN POLICY CHALLENGES.

Roberta De Santis, Piero Esposito and Cecilia Jona Lasinio

Working Paper No. 153
February 2020

Luiss Lab of European Economics
Department of Economics and Business
LUISS Guido Carli
Viale Romania 32, 00197, Rome -- Italy
http://dptea.luiss.edu/research-centers/luiss-lab-european-economics

Environmental regulation and productivity growth: main policy challenges.

R. De Santis, P. Esposito and C. Jona Lasinio[1]

(February 2020)

Abstract

In this paper, we empirically analyse the environmental regulation-productivity nexus for 14 OECD countries in the period 1990-2013. Our findings support the hypothesis that environmental policies have a productivity growth enhancing effect through innovation as suggested by Porter and Van Der Linde (1995). We provide evidence that both market and non-marked based policies foster labour and multifactor productivity growth and that the positive association is better captured by environmental adjusted productivity indicators. Moreover, we find that productivity increases resulting from changes in the environmental regulation pass through a stimulus to capital accumulation and this effect is concentrated in high ICT intensive countries. Overall, the need to speed up the transition towards a "green economy" for environmental protection purposes can be seen also as an opportunity to improve competitiveness generating a virtuous circle between innovation and environmental friendly production techniques.

Keywords: environmental regulation, productivity, innovation, Porter hypothesis,

JEL Code: D24, Q50, Q55, O47, O31

[1] Corresponding author: rdesantis@istat.it (Italian National Statistical Institute and Luiss University), cjonalasinio@luiss.it (Italian National Statistical Institute and LUISS University), pesposito@luiss.it (University of Cassino and Southern Lazio; Luiss School of European Political Economy). The views expressed in this paper are those of the authors and do not necessarily represent the institutions with which they are affiliated. Any errors or mistakes remain the authors' sole responsibility.

I Introduction

The environmental regulation-competitiveness nexus is a significant challenge to policymakers. It became central in the international policy debate especially after the global financial crisis when the so-called “green economy” and “green new deal” paradigms emerged.

The investigation of the mechanisms through which environmental policy influences innovation and productivity, as well as the factors strengthening this relationship, is key to implement compelling policies fostering environmentally sustainable productivity growth. In fact in this context, the role of policies is pivotal as both pollution and innovation generate market failures requiring a well-designed public intervention to avoid that firms pollute too much and innovate too little compared with the social optimum.

The aim of this paper is to provide a contribution in this respect testing the so called Porter Hypothesis (PH) for 14 OECD countries in the period 1990-2013. More precisely, we consider the three versions of the PH, namely the weak, strong, and narrow (Jaffe and Palmer 1997). The weak form hypothesizes that regulation induces innovation, which in turn stimulates productivity. However, productivity might not improve, because the opportunity costs of additional innovation offset the productivity gains. The strong version suggests instead that the benefits coming from product and process innovation induced by environmental regulation overcome their costs eventually raising the overall productivity. Finally, the narrow version assumes that, market-based instruments, such as taxes or tradable permits, are more likely to induce innovation and productivity growth as they leave more freedom to the firm in terms of the choice of the technological solution to minimize compliance costs than non-marked based instruments.[2]

Empirical evidence on the consequences of environmental regulations at the macroeconomic level is rather scant. Furthermore, existing studies are heterogeneous and developed mainly in the context of international trade. Empirical findings are typically very context-specific and focused on different indicators of efficiency and innovation (e.g. multifactor productivity, patent counts or efficiency score). Consequently, the size and the sign of the identified effects are hardly comparable.

Only few studies, testing the different Porter Hypotheses, documented the effect of more stringent environmental regulation on productivity and environmental innovation adopting a

[2] Fischer, Parry and Pizer (2003), Jaffe and Palmer (1997).

cross-country perspective but the empirical evidence is still inconclusive[3]. Some authors argue that despite improving the environment, stricter environmental policies may imply additional costs for pollution abatement, alter investment decisions, and restrict inputs in the production process as well as the set of available technologies (Ambec et al. 2013, Dechezleprêtre and Sato 2017). Consequently, at least in the short-run, higher compliance costs may decrease international competitiveness and reduce productivity growth.

Other papers suggest that well-designed environmental regulations can improve competitiveness along with environmental quality, by promoting product and process innovation (Ambec and Barla 2002; André et al. 2009). For instance, in the case of spillovers in the innovation and technology adoption process, a stricter environmental policy can increase firms' productivity by internalizing the positive externalities (Greaker 2006; Mohr 2002).

There is also ample empirical evidence that well-designed environmental policy tends to bring about positive effects on innovation (Carrión-Flores and Innes 2010; Lanoie et al. 2011), but the impact on productivity growth remains ambiguous (Brännlund and Lundgren 2009; Cohen and Tubb 2018). Albrizio et al (2017) look at the effect of environmental stringency policy changes on productivity growth in the OECD countries. They experiment a new environmental policy stringency (EPS) index, and test a reduced-form model of multi-factor productivity growth, that takes into account that the effect of environmental policy measures varies with industry pollution intensity and technological advancement. Their results suggest that a tightening of environmental policy is associated with a short-term increase in industry level productivity growth only in the most technologically-advanced countries.

Other recent studies find more robust support for the strong PH (Ambec et al. 2013; Franco and Marin 2017; Yang et al. 2012) but the results for the weak and narrow PHs remain ambiguous. For example, De Santis and Jona Lasinio (2016) using a panel data approach found that the "narrow" Porter hypothesis cannot be rejected and that the choice of the policy instruments might not be neutral. In particular, market based environmental measures appear as the most suitable instrument to stimulate innovation and productivity growth.

More recently, Martinez Zarzoso et al (2019), use panel data models and quantile regressions to test the "weak" and "strong" Porter hypotheses, for 14 OECD countries over the period 1990-2011. Consistently with the weak hypothesis, their findings indicate that stringent

[3] For a recent survey see Martinez Zarzoso et al. 2019.

environmental regulations exert a positive influence on R&D expenditure, the number of patent applications and total factor productivity.

Our contribution to the previous literature is threefold. First, we adopt a country-level analysis to capture the variation both across policies and across outcomes, as well as possible spillover effects. Compared to industry or firm level studies, which suffer from the lack of generality as they usually provide very context-specific conclusions, a country-level approach is best suited for international policy-making,

Second, we test the impact of standard versus environmental adjusted indicators on the PH models, assuming that measurement issues might affect our results. To the best of our knowledge, research work testing the Porter hypotheses uses standard productivity indicators and does not consider the possible measurement bias determined by the lack of an "environmental adjustment" of output and inputs[4].

Third, in our analysis we disentangle the effect of ICT and non-ICT capital being the latter a key variable in the Porter hypothesis prescriptions. Moreover, to analyse more in depth the role of ICT capital we estimate the impact of EPS separately for high and low ICT-intensive countries.

Our findings support the hypothesis that environmental policies in OECD countries had a productivity growth-promoting effect. We found evidence that both market and non-marked based policies had a positive impact on productivity. Moreover, we show that, with no exceptions, the positive association is better captured by environmental adjusted productivity indicators suggesting that measurement issues are relevant in addressing the environmental regulation-competitiveness nexus. Eventually, we found that productivity increases resulting from changes in the environmental regulation pass through a stimulus to capital accumulation and that this effect is concentrated in high ICT intensive countries.

The paper is organized as follows: section II describes the data and shows some descriptive analysis, section III illustrates the empirical strategy. Sections IV and V provides estimation results and robustness checks. Conclusions follow.

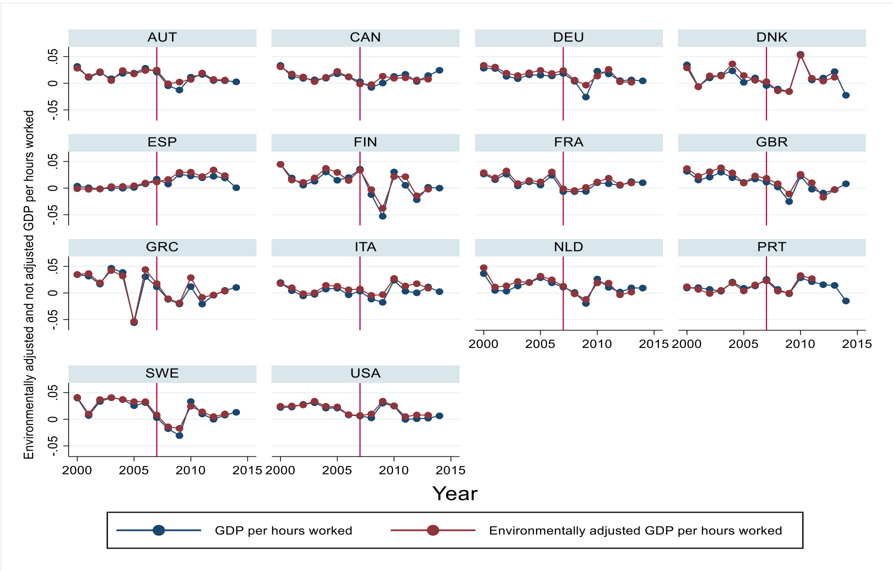
4 These measures are biased for two reasons. First, while income generated with domestic natural assets is fully reflected, no account is taken of the natural resource input (in terms of the resource rents). Increased natural resource use is therefore wrongly interpreted as a rise in productivity. Second, while the costs of investing in pollution abatement are fully captured (in terms of factor inputs including labour and produced capital), no account is taken of the benefits of such investments because pollution is not considered as an output of the production process. Increased abatement efforts therefore make productivity appear falsely low. (See Brandt et al., 2014; 2013).

II Dataset and descriptive analysis

Our analysis covers 14 OECD economies (Austria, Canada, Denmark, Finland, France, Germany, Greece, Italy, Portugal, Spain, Sweden, The Netherlands, UK and USA). These countries have been selected as they have closely followed the OECD environmental guidelines. Notice that the OECD has been very active in the design of effective environmental regulation policies since the beginning of the 1970s[5].

In this paper we focus on productivity as a measure of competitiveness[6] and we distinguish between standard versus environmental adjusted productivity indicators (Figure 1)[7].

Figure 1- Comparing environmentally adjusted and not adjusted labor productivity growth



Source: OECD

In particular, we measure environmental adjusted labor productivity as environmental adjusted GDP for pollution abatement per hour terms. Adjustments are affected by country's technological capabilities (e.g. innovative ways to abate pollution) and changes in economic structure (e.g. less emission-intensive industries). The comparison between the adjusted and unadjusted indicator of productivity is not straightforward as it can be affected by a wide range of policy and market factors.

---

[5] The OECD strongly supported the achievement of the two United Nations climate treaties. The OECD was also among the main promoters of the Paris Agreement at the COP21 in Paris, which went into force in November of 2016.

[6] Other studies have analyzed the effects of environmental regulation on several different measures of competitiveness (i.e. impacts on business performance, trade flows, FDI, and employment).

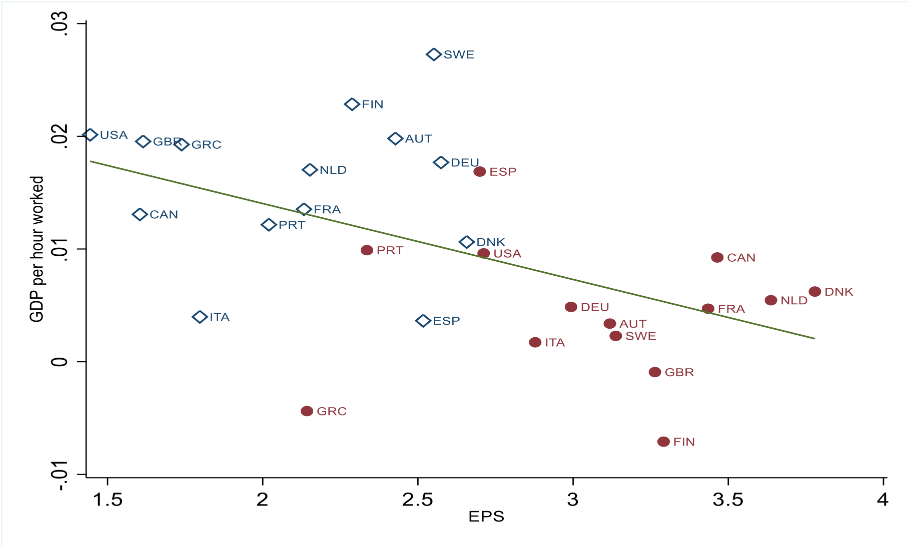
[7] The latter accounts also for the use of natural capital (currently including 14 types of fossil fuels and minerals) and for the emission of pollutants as negative by-products (currently including 8 types of greenhouse gases and air pollutants).

As for environmental stringency indicators, we use the Environmental Policy Stringency (EPS) composite index, developed for the OECD countries by Botta and Koźluk (2014)[8]. It is particularly suitable to test Narrow Porter Hypothesis since it distinguishes between: i) market-based instruments providing market incentives to the reduction or removal of negative environmental externalities and ii) non market based instruments that are mostly regulatory provisions.

Figure 2 and 3 display the average growth of unadjusted and adjusted productivity measures versus the EPS index before and after the global financial crisis.

Figure 2 - Labor productivity growth vs EPS

(1999-2007 blue open diamonds; 2008-2016 red closed circles)



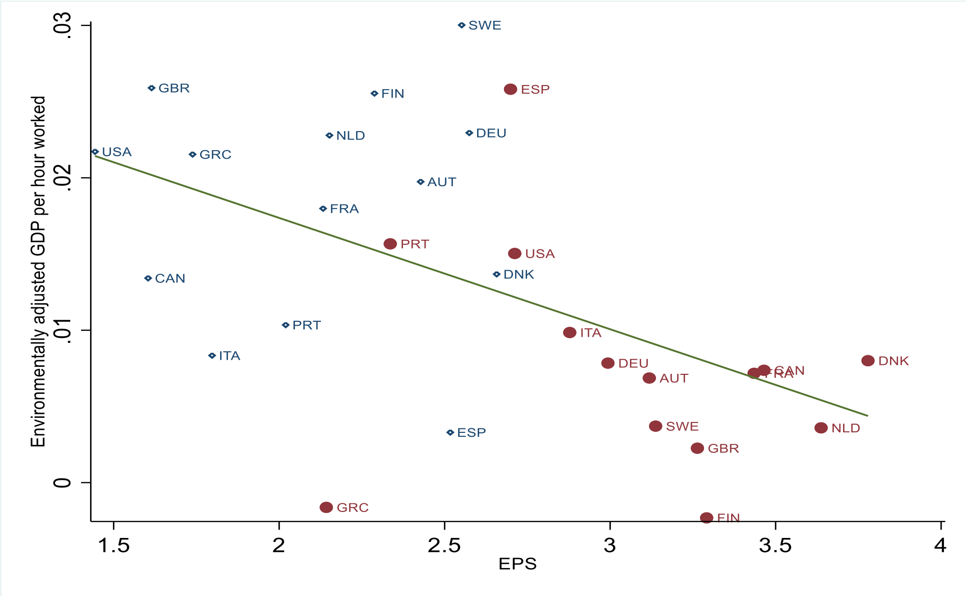
Source: OECD

In both cases, there is a negative relation between productivity growth and environmental policy stringency. However, this relation is likely to be affected by the generalized slowdown of GDP growth following the global financial crisis in a context of increasing environmental policy stringency. Hence, the simple bivariate evidence does not provide ultimate indications on the direction of the relationship. In the next paragraph we describe our empirical strategy to evaluate this relationship using econometric techniques.

[8] The EPS covers 24 OECD countries over the period 1990-2013. The indicator is based on the taxonomy developed by De Serres et al. (2010) and the sub-components are all weighted equally. A market-based subcomponent groups instruments, which assign an explicit price to the externalities (taxes: CO2, SOX, NOX, and diesel fuel; trading schemes: CO2, renewable energy certificates, energy efficiency certificates; feed in- tariffs; and deposit-refund-schemes), while the non-market component clusters command-and-control instruments, such as standards (emission limit values for NOX, SOX, and PM, limits on Sulphur content in diesel), and technology-support policies, such as government R&D subsidies.

Figure 3 - Environmentally adjusted labor growth productivity vs EPS

(1999-2007 blue open diamonds; 2008-2016 red closed circles)



Source: OECD

III. Econometric model and strategy

To test the Porter Hypotheses (PH), we use a Panel VAR (PVAR) approach consisting in a system of equations where each variable is expressed as a dynamic function of lagged values of (endogenous) variables. This approach, alongside single equation GMM-based dynamic panels, became standard in the estimation of production function coefficients as it controls for reverse causality and simultaneity bias among variables. These endogeneity issues are typical features of production functions where inputs are jointly determined with output. As for the relation between Environmental policy stringency index (EPS) and productivity, endogeneity issues might stem from measurement errors and unobserved components affecting both environmental regulation and productivity growth (Mobius 2018).

The Panel VAR representation as a system of equations is the following:

$$\Delta Prod_{i,t}^{k} = \beta_0 \Delta Prod_{i,t-1} + \beta_1 \Delta kict_{i,t-1} + \beta_2 \Delta knoict_{i,t-1} + \beta_3 \Delta EPSI_{i,t-1}^{j} + \varepsilon_{i,t}^{1} \quad (2a)$$

$$\Delta kict_{i,t} = \beta_4 \Delta Prod_{i,t-1}^{k} + \beta_5 \Delta kict_{i,t-1} + \beta_6 \Delta knoict_{i,t-1} + \beta_7 \Delta EPSI_{i,t-1}^{j} + \varepsilon_{i,t}^{2} \quad (2b)$$

$$\Delta knoict_{i,t} = \beta_8 \Delta Prod_{i,t-1}^{k} + \beta_9 \Delta kict_{i,t-1} + \beta_{10} \Delta knoict_{i,t-1} + \beta_{11} \Delta EPSI_{i,t-1}^{j} + \varepsilon_{i,t}^{3} \quad (2c)$$

$$\Delta EPS_{i,t} = \beta_8 \Delta Prod_{i,t-1}^{k} + \beta_{13} \Delta kict_{i,t-1} + \beta_{14} \Delta knoict_{i,t-1} + \beta_{15} \Delta EPSI_{i,t-1}^{j} + \varepsilon_{i,t}^{4} \quad (2d)$$

where *Prod* refers to the log of four different (k=4) productivity indicators: environmentally adjusted labour productivity (output per hour worked, *HLPea*); unadjusted labour productivity (*HLP*); environmentally adjusted multifactor productivity (*MFPea*); unadjusted multifactor productivity (*MFP*).

As for the regressors, *kict* is the log-stock of ICT capital and *knoict* is the log-stock of non-ICT capital both per hour worked in volume terms. EPSIj is our environmental legislation indicator, with j changing from 1 to 8, where: j_1= total EPS index (EPSI), j_2= Market Based EPS (EPSIMB); j_3= Non-Market Based EPS (EPSINMB); j_4= taxes (TAX); j_5= Feed in tariffs (FIT); j_6= Trading Schemes (TS); j_7= Standards (STD); and j_8= R&D Subsidies (RDS).

The Panel VAR system of equations (2a)-(2d) is estimated with a GMM approach where lagged variables are instrumented with their first lag. In this way the equations are exactly identified, thus avoiding the excessive proliferation of instruments typical of GMM-based approaches.[9]

Once estimated the VAR coefficients, we are able to investigate the dynamic impact of an exogenous shock in EPS (i.e. a shock on $\varepsilon^4_{i,t,}$) though impulse-response functions (IRF). In order to consider the shock exogenous, we need an identification strategy on the way the shock affects EPS and the other variables. Our strategy for IRFs estimation is based on the Cholesky decomposition whereby a shock in the EPS affects capital stocks and productivity with a lag.

IV. Regressions results and robustness checks.

The results of the Panel VAR estimates of equation (1) on labour productivity are shown in Table 1. To the sake of simplicity, we show the results for the productivity equation (2a). Estimated coefficients represent the initial impact of a shock on a specific variable and are similar to IRF in the case of no persistence of the shocks only.

The results confirm the validity of the augmented production function estimates: both ICT and non-ICT capital intensity coefficients are positive and significant coherently with the empirical literature (Spiezia, 2012; Timmer et al. 2010).

The EPS coefficient is positive and significant for the environmentally adjusted productivity only. The decomposition of the index in its various components[10] shows that the result is driven by non-market based measures (columns 3-7).

[9] The estimation procedure transforms variables in forward orthogonal deviation to eliminate fixed effects and removes cross sectional dependence (CSD) by using cross sectional averages of all variables.
[10] See footnote 7 above.

Table 1 Estimation results for equation (2a) with labour productivity

	EPSI		EPSIMB		EPSINMB		TAX	
	HLPea	HLP	HLPea	HLP	HLPea	HLP	HLPea	HLP
$\Delta prod_{t-1}$	0.443***	0.357**	0.422***	0.346**	0.434***	0.352**	0.424***	0.359***
	[0.107]	[0.109]	[0.110]	[0.110]	[0.104]	[0.107]	[0.105]	[0.108]
$\Delta knoict_{t-1}$	0.138*	0.176**	0.142*	0.180**	0.152**	0.186**	0.129*	0.166**
	[0.078]	[0.076]	[0.079]	[0.078]	[0.077]	[0.077]	[0.078]	[0.076]
$\Delta kict_{t-1}$	0.018*	0.018*	0.021**	0.020*	0.019*	0.019*	0.022**	0.021*
	[0.010]	[0.010]	[0.010]	[0.010]	[0.010]	[0.010]	[0.010]	[0.011]
ΔEPS_{t-1}	0.010**	0.006	0.004	0.002	0.006**	0.004	0.009	0.011
	[0.004]	[0.004]	[0.004]	[0.004]	[0.002]	[0.002]	[0.007]	[0.007]
N	242	255	242	255	242	255	242	255
	FIT		RDS		STD		TS	
	HLPea	HLP	HLPea	HLP	HLPea	HLP	HLPea	HLP
$\Delta prod_{t-1}$	0.415***	0.349***	0.423***	0.346**	0.421***	0.347**	0.445***	0.369***
	[0.103]	[0.105]	[0.109]	[0.110]	[0.103]	[0.106]	[0.097]	[0.102]
$\Delta knoict_{t-1}$	0.157**	0.193**	0.157**	0.188**	0.145*	0.184**	0.136*	0.170**
	[0.077]	[0.078]	[0.078]	[0.078]	[0.075]	[0.076]	[0.077]	[0.076]
$\Delta kict_{t-1}$	0.023**	0.022**	0.020**	0.020*	0.021**	0.020*	0.021**	0.020*
	[0.010]	[0.011]	[0.010]	[0.011]	[0.010]	[0.011]	[0.010]	[0.010]
ΔEPS_{t-1}	-0.002	-0.002	0.002	0.001	0.004*	0.003*	0.004**	0.003**
	[0.002]	[0.002]	[0.001]	[0.002]	[0.002]	[0.002]	[0.002]	[0.001]
N	242	255	242	255	242	255	242	255

*significant at 10% level; significant at 5% level; significant at 1% level. EPS=environmental protection stringency; averages; EPSIMB=market based EPS index; EPSINMB=non-market based EPS index; TAX=environmental taxation index; FIT=feed in tariffs index; RDS=R&D subsidies index; STD= environmental standards index; TS= trading schemes index; kict=log-ICT capital per hour worked; knoict=log non-ICT capital per hour worked.

However if we consider the EPS sub-components both standards (non-market measure) and trading schemes (market-based measure) display a positive and significant coefficient with similar magnitude. This suggests that the narrow PH cannot be validated at this stage.

In Table 2, we show the results for the multifactor productivity equation. We find that: i) both ICT and non-ICT capital intensity are significant, their coefficients are larger than those shown in table 1 and coherent with the empirical literature; ii) the impact of ICT is always larger when considering the environmentally adjusted MFP indicator; iii) EPS measures coefficients are significant and both market-based and non-market based environmental policies are positively correlated with productivity (the narrow PH once again is not validated).

However, looking at the EPS subcomponents (differently from the estimates on labour productivity) also taxes turn significant (alongside standards and trading schemes).

Table 2 Estimation results for equation (2a) with Multifactor Productivity, Panel VAR

	EPS		EPS MKT		EPS NMKT		TAXES	
	MFPea	MFP	MFPea	MFP	MFPea	MFP	MFPea	MFP
$\Delta prod_{t-1}$	0.662***	0.349***	0.632***	0.333**	0.640***	0.342***	0.638***	0.362***
	[0.093]	[0.104]	[0.091]	[0.107]	[0.094]	[0.104]	[0.088]	[0.106]
$\Delta knoict_{t-1}$	0.201**	0.197**	0.204**	0.202**	0.221**	0.208**	0.189**	0.185**
	[0.087]	[0.079]	[0.087]	[0.079]	[0.089]	[0.080]	[0.086]	[0.079]
$\Delta kict_{t-1}$	0.028**	0.021**	0.032**	0.023**	0.030**	0.021**	0.032***	0.023**
	[0.010]	[0.010]	[0.010]	[0.010]	[0.010]	[0.010]	[0.010]	[0.010]
ΔEPS_{t-1}	0.012**	0.006*	0.006*	0.002	0.006**	0.004*	0.012*	0.010**
	[0.004]	[0.003]	[0.004]	[0.003]	[0.003]	[0.002]	[0.006]	[0.005]
N	242	255	242	255	242	255	242	255
	FIT		RDS		STD		TS	
	MFPea	MFP	MFPea	MFP	MFPea	MFP	MFPea	MFP
$\Delta prod_{t-1}$	0.611***	0.330**	0.626***	0.331**	0.620***	0.339**	0.635***	0.350***
	[0.092]	[0.104]	[0.094]	[0.106]	[0.092]	[0.103]	[0.090]	[0.100]
$\Delta knoict_{t-1}$	0.224**	0.216**	0.226**	0.210**	0.215**	0.204**	0.212**	0.196**
	[0.089]	[0.081]	[0.089]	[0.080]	[0.088]	[0.080]	[0.088]	[0.079]
$\Delta kict_{t-1}$	0.033**	0.024**	0.031**	0.022**	0.032**	0.023**	0.032**	0.022**
	[0.011]	[0.010]	[0.010]	[0.010]	[0.010]	[0.010]	[0.011]	[0.010]
ΔEPS_{t-1}	0.000	-0.002	0.002	0,001	0.004**	0.003*	0.004*	0.003*
	[0.002]	[0.002]	[0.002]	[0.001]	[0.002]	[0.002]	[0.002]	[0.002]
N	242	255	242	255	242	255	242	255

*significant at 10% level; significant at 5% level; significant at 1% level. EPS=environmental protection stringency; averages; EPSIMB=market based EPS index; EPSINMB=non-market based EPS index; TAX=environmental taxation index; FIT=feed in tariffs index; RDS=R&D subsidies index; STD= environmental standards index; TS= trading schemes index; kict=log-ICT capital per hour worked; knoict=log non-ICT capital per hour worked.

Thus two market-based measure exert a significant impact on productivity whereas the effect of non-market based measures is driven by standards only. Moreover, the taxes coefficient is of greater magnitude than that of standards providing some evidence in favour of the narrow PH. These results, are coherent with De Santis and Lasinio (2016).

Environmental adjusted indicators once again seem to be more suitable that standard productivity measures in capturing the effects of the transmission mechanism suggested by the PH.

Finally, in Tables 3, to analyse more in depth the role of ICT capital we report the Panel VAR estimates of equations (2a)-(2d) where the impact of EPS is estimated separately for high and low ICT-intensive countries.

The grouping is made according to the average level of ICT capital per hour worked. High ICT countries are those with above average ICT intensity while the remaining countries are classified as low ICT. [11]

Table 3 Panel VAR estimates for equation (2a), with EPS impacts divided into high and low ICT countries.

	HLP ea			HLP		
	ESPI	EPS MKT	EPS NMKT	EPSI	EPS MKT	EPS NMKT
Δ$prod_{t-1}$	0.438***	0.422***	0.432***	0.361**	0.356**	0.351**
	[0.108]	[0.108]	[0.103]	[0.110]	[0.108]	[0.108]
Δ$knoict_{t-1}$	0.139*	0.145*	0.152**	0.179**	0.188**	0.185**
	[0.077]	[0.079]	[0.077]	[0.075]	[0.078]	[0.077]
Δ$kict_{t-1}$	0.018*	0.021**	0.019*	0.017*	0.020*	0.018*
	[0.010]	[0.010]	[0.010]	[0.010]	[0.011]	[0.010]
Δ$EPShi_{t-1}$	0.014**	0.008	0.006**	0.013**	0.009	0.005
	[0.006]	[0.006]	[0.003]	[0.007]	[0.006]	[0.003]
Δ$EPSlow_{t-1}$	0.004	-0.001	0.005	-0.002	-0.005	0.002
	[0.004]	[0.004]	[0.004]	[0.004]	[0.003]	[0.003]
	242	242	242	255	255	255
	MFP EA			MFP		
	ESPI	EPS MKT	EPS NMKT	ESPI	EPS MKT	EPS NMKT
Δ$prod_{t-1}$	0.660***	0.632***	0.638***	0.350***	0.339**	0.340***
	[0.093]	[0.091]	[0.093]	[0.104]	[0.105]	[0.103]
Δ$knoict_{t-1}$	0.202**	0.205**	0.221**	0.199**	0.208**	0.207**
	[0.086]	[0.087]	[0.088]	[0.078]	[0.080]	[0.080]
Δ$kict_{t-1}$	0.028**	0.032**	0.029**	0.020**	0.023**	0.021**
	[0.010]	[0.010]	[0.010]	[0.010]	[0.010]	[0.010]
Δ$EPShi_{t-1}$	0.014**	0.008	0.007*	0.011**	0.006	0.005*
	[0.007]	[0.006]	[0.004]	[0.005]	[0.005]	[0.003]
Δ$EPSlow_{t-1}$	0.009**	0.004	0.005	0	-0.002	0.002
	[0.005]	[0.004]	[0.005]	[0.004]	[0.003]	[0.003]
N	242	242	242	255	255	255

*significant at 10% level; significant at 5% level; significant at 1% level. EPS=environmental protection stringency; averages; EPSIMB=market based EPS index; EPSINMB=non-market based EPS index; kict=log-ICT capital per hour worked; knoict=log non-ICT capital per hour worked.

The results are coherent with Albrizio et al (2017) and confirm our assumptions: EPS is positive and significant in high ICT intensive countries whereas, with few exceptions, it is not significant

[11] High ICT capital countries are Austria, Germany, Denmark, Finland, France, the Netherlands and Sweden; low ICT capital countries are Canada, Span, UK, Greece, Italy, Portugal and USA. The dichotomization of the impact allows to avoid the introduction of non-linear terms (i.e. the interaction between EPS and ICT levels) and maintain the methodology simple and intuitive. Cross validation analyses (available upon request) show that estimated coefficients are mostly insensitive to group switches of countries close to the average value.

in low ICT intensive countries. Overall, these findings suggest that ICT capital is a relevant factor to exploit productivity gains form stricter environmental regulations.

Despite this finding does not directly validate the weak PH, it is coherent with the assumption that investment in high tech capital allows countries to better exploit the innovations opportunities given by changes in the stringency of environmental regulations.

V. Impulse-response analysis

Panel VAR coefficients do not properly account for the impact of an exogenous shock on EPS. They represent the impact in t+1 on a shock in t but do not capture the persistence of the shock and the feedback loops from the other variables. To obtain a reliable measure of the effect of EPS on productivity, we need to estimate impulse response functions, calculated using a Cholesky decomposition where the chain of causality is the following: EPS → Kict→Knoict→Prod.

IRFs figures are shown in the Appendix (Figures A2-A5) and confirm the coherence with the estimated coefficients: a shock to EPS affects significantly productivity in the following period while from t+2 onwards the effect fades to zero; a similar result is found for *knoict* although the significance is lower; finally, the impact on *kict* is first positive and then negative but, in both cases, highly insignificant.

To summarize the main results, in Table 4 we show the responses after 10 years to a shock in EPS considering the four productivity measures and splitting the impact of EPS into high and low ICT intensive countries. The total impact of a standard deviation increase in EPS on the standard deviation of productivity is 0.041 for *MFPea* and 0.018 for *HLPea*. Unadjusted measures show smaller and similar impacts (0.013).

The effect of EPS on *Knoict* ranges between 0.011 and 0.023 and the latter's impact on productivity is between 0.653 and 1.412. The high response of productivity to non-ICT capital suggests that a non-negligible part of the effect of EPS on productivity takes place indirectly through capital accumulation.

Turning to the distinction between high and low ICT countries (middle and lower panels of Table 4), we find that the final impact of a shock to EPS on productivity ranges between 0.017 and 0.050 in high ICT countries and between 0 and 0.023 in low ICT countries. High ICT countries also show larger impacts of EPS on Knoict.

Table 4 Impulse response functions from equation (1): responses after 10 years

	EPS on Prod	Kict	Knoict	Kict on Prod	Knoict on Prod
HLP ea	0.018	-0.011	0.011	0.059	0.653
HLP	0.013	-0.004	0.015	0.061	0.779
MFP ea	0.041	-0.033	0.023	0.142	1.412
MFP	0.013	-0.005	0.017	0.066	0.836
	High ICT countries				
	EPS on Prod	Kict	Knoict	Kict on Prod	Knoict on Prod
HLP ea	0.017	-0.007	0.012	0.059	0.594
HLP	0.024	0.003	0.022	0.057	0.729
MFP ea	0.05	-0.028	0.03	0.137	1.373
MFP	0.022	-0.001	0.025	0.063	0.802
	low ICT countries				
	EPS on Prod	Kict	Knoict	Kict on Prod	Knoict on Prod
HLP ea	-0.004	-0.007	0.012	0.059	0.594
HLP	-0.002	-0.005	0.005	0.057	0.729
MFP ea	0.027	-0.041	0.012	0.137	1.373
MFP	0.002	-0.01	0.006	0.063	0.802

In conclusion, our evidence suggest that productivity growth triggered by environmental regulation pass through a stimulus to capital accumulation concentrated in high ICT intensive countries. This result is coherent with the strong HP.

VI Conclusions

Our empirical analysis suggest that the need to speed up the transition towards a "green economy" for environmental protection purposes can be seen also as an opportunity to improve competitiveness.

According to our estimates, for the OECD countries in the period 1993-2015, the strong Porter hypothesis cannot be rejected: environmental policies had a productivity growth-promoting effect. Both market and non-marked based environmental policies exerted a positive impact on labour and multifactor productivity growth.

Moreover, although the narrow Porter hypothesis cannot be fully validated, among environmental policies subcomponents, green taxes is the one displaying the impact of greatest magnitude on multifactor productivity.

We also found that productivity increases resulting from changes in the environmental regulation pass through a stimulus to capital accumulation especially in high ICT intensive countries. Despite this finding does not directly validate the weak PH, it is coherent with the assumption that investment in high tech capital allows countries to better exploit the innovations opportunities given by changes in the stringency of environmental regulations (as implied in the weak PH).

Overall, the correct measurement of environmental spillovers arising from production processes seems to have a relevance to address effectively the policy debate. In fact, in our estimates environmental adjusted indicators proved, with no exception, to be more suitable than standard indicators in capturing the transmission mechanism effects between environmental policy and productivity. Capital accumulation appears biased towards clean methods of production, as productivity-increasing effects are larger when properly taking into account negative environmental effects associated with the production process.

References

Albrizio S., Koźluk T and V. Zipperer, (2014). "Empirical Evidence on the Effects of Environmental Policy Stringency on Productivity Growth," OECD Economics Department Working Papers 1179, OECD Publishing.

Ambec S, Cohen M., Elgie S. and P Lanoie (2011) The Porter Hypothesis at 20: Can Environmental Regulation Enhance Innovation and Competitiveness? RF Discussion Paper 11-01, Washington DC: Resources for the Future

Ambec S., Barla P., (2002) A theoretical foundation of the Porter Hypothesis. Economic letters 75: 355-360.

André FJ, González P, Porteiro N (2009) Strategic quality competition and the Porter hypothesis. J Environ Econ Manag 57(2):182–194

Botta, E. and T. Koźluk (2014), "Measuring Environmental Policy Stringency in OECD Countries – A Composite Index Approach", OECD Economics Department Working Paper, No. 1177, OECD Publishing.

Brandt N., P. Schreyer and V. Zipperer (2014), "Productivity Measurement with Natural Capital and Bad Outputs", OECD Economics Department Working Papers, No. 1154, OECD Publishing

Runar Brännlund and Tommy Lundgren (2009), "Environmental Policy Without Costs? A Review of the Porter Hypothesis", International Review of Environmental and Resource Economics: Vol. 3: No. 2, pp 75-117. http://dx.doi.org/10.1561/101.00000020

Carrion-Flores C., Innes R (2010) Environmental innovation and environmental performance J. Environ. Econ. Manag. 59: 27–4

Cohen MA, Tubb A (2018) The impact of environmental regulation on firm and country competitiveness: a meta-analysis of the Porter hypothesis. J Assoc Environ Resour Econ 5(2):371–399

Dechezleprêtre A, Sato M (2017), The impacts of environmental regulations on competitiveness. Rev Environ Econ Policy 11(2):183–206

De Santis R. and C. Jona Lasinio, (2016), Environmental Policies, Innovation and Productivity in the EU, The Global Economy Journal.

de Serres, A., F. Murtin and G. Nicoletti (2010), “A Framework for Assessing Green Growth Policies”, OECD Economics Department Working Papers, No. 774, OECD.

Fischer, C., I. W. H. Parry, and W. A. Pizer. 2003. “Instrument Choice for Environmental Protection When Technological Innovation Is Endogenous.” Journal of Environmental Economics and Management 45:523–45.

Franco C, Marin G (2017), The effect of within-sector, upstream and downstream environmental taxes on innovation and productivity. Environ Resour Econ 66(2):261–291

Greaker M (2006) Spillovers in the development of new pollution abatement technology: a new look at the Porter-hypothesis. J Environ Econ Manag 52(1):411–420

Jaffe, A. B. and K. Palmer (1997), “Environmental Regulation and Innovation: A Panel Data Study”, The Review of Economics and Statistics, Vol. 79(4), pp. 610-619

Kapetanios, G., Pesaran, M.H., Yamagata. T., 2011. Panels with non-stationary multifactor error structures. J. Econom., 160(2), 326-348.

Koluk T, Zipperer V (2014) źnvironmental Policies and Productivity Growth: A Critical Review of Empirical Findings OECD Journal: Economic Studies, 1:2014

Lanoie P., Patry M., Lajeunesse R (2008) Environmental regulation and productivity: testing the Porter Hypothesis. J. Prod. Anal. 30: 121–128.

Lanoie P., Laurent-Lucchetti J., Johnstone N., Ambec S. (2011) Environmental policy, innovation and performance: new insights on the Porter Hypothesis. J. Econ. Manag. Strategy 20: 803–842.

Managi, S., Opaluch, J.J., Jin, D. and Grigalunas, T.A. (2005). Environmental regulations and technological change in the offshore oil and gas industry. Land Economics, 81, 303-319

Martinez Zarzoso et al (2019). Does environmental policy stringency foster innovation and productivity in OECD countries?, Energy Policy, Volume 134, November 2019

Mohor R., (2002) Technical Change, External Economies, and the Porter Hypothesis. Journal of Environmental economics and management 43: 158-168.

OCSE (2018)

Porter M., (1991) America's green strategy. Sci. Am. 264, 168.

Porter M., Van Der Linde C., (1995) Toward a New Conception of the Environment-Competitiveness Relationship, Journal of Economic Perspectives 9(4): 97–118

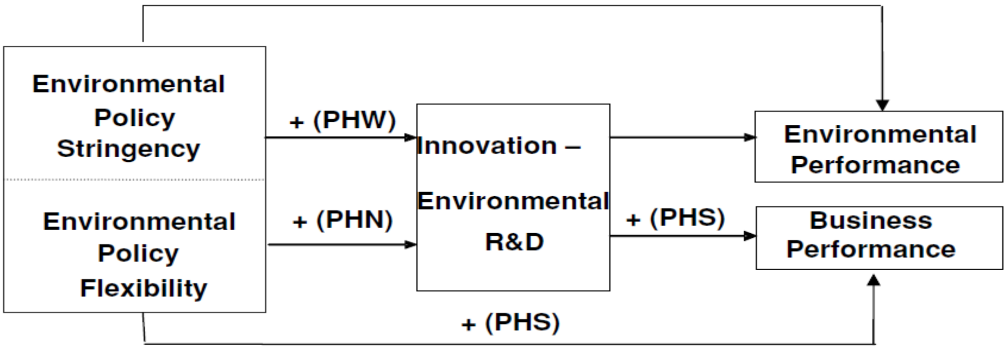
Spiezia, V. (2012), ICT investments and productivity: Measuring the contribution of ICTS to growth. OECD Journal of Economic Studies, Vol. 2012/1.

Timmer, M. P., Robert Inklaar, M. O'Mahony and B. van Ark (2010),Economic Growth in Europe: A Comparative Industry Perspective, Cambridge University Press.

Yang CH, Tseng YH, Chen CP (2012) Environmental regulations, induced R&D, and productivity: evidence from Taiwan's manufacturing industries. Resour Energy Econ 34(4):514–532

Appendix

Figure A1 The Porter hypotheses causality chains



Source: Lanoie et al (2011)

Table A1. Data description

Variable	Description	Source
HLP ea	Environmentally adjusted hourly labour productivity growth: growth of environmentally adjusted GDP minus growth of total hours worked	OECD
HLP	Hourly labour productivity growth: growth of GDP per hour worked	OECD
kict	ICT capital stock per hour worked (in logs)	OECD, EUKLEMS
knoict	Non-ICT capital stock per hour worked (in logs)	OECD, EUKLEMS
EPSI	Environmental Policy Stringency Index	OECD
EPSIMB	Market-based Environmental Policy Stringency index	OECD
EPSINMB	Non Market-based Environmental Policy Stringency index	OECD
TAX	Environmental Policy Stringency Index: Taxation policy	OECD
FIT	Environmental Policy Stringency Index: Feed in tariffs policy	OECD
RDS	Environmental Policy Stringency Index: R&D subsidies policy	OECD
STD	Environmental Policy Stringency Index: Standards policy	OECD
TS	Environmental Policy Stringency Index: Trading Schemes policy	OECD

Table A2. Descriptive statistics

	mean	s.d.	min	max
Δhlp_ea	0.016	0.015	-0.054	0.060
Δhlp	0.013	0.016	-0.056	0.061
Δkict	0.041	0.109	-0.886	0.242
Δknoict	0.039	0.022	-0.033	0.145
ΔEPS	0.102	0.295	-0.633	1.113
ΔEPS_MKT	0.070	0.377	-1.167	2.083
ΔEPS_NMKT	0.133	0.453	-1	1.875
ΔTAXES	0.014	0.237	-0.5	1.5
ΔRD_SUB	0.063	0.716	-2	3
ΔSTD	0.203	0.549	0	3.5
ΔFIT	0.111	0.908	-4	5.5
ΔTRADESCH	0.086	0.749	-2	2.6

Figure A2 Response to a shock in EPS: HLP EA

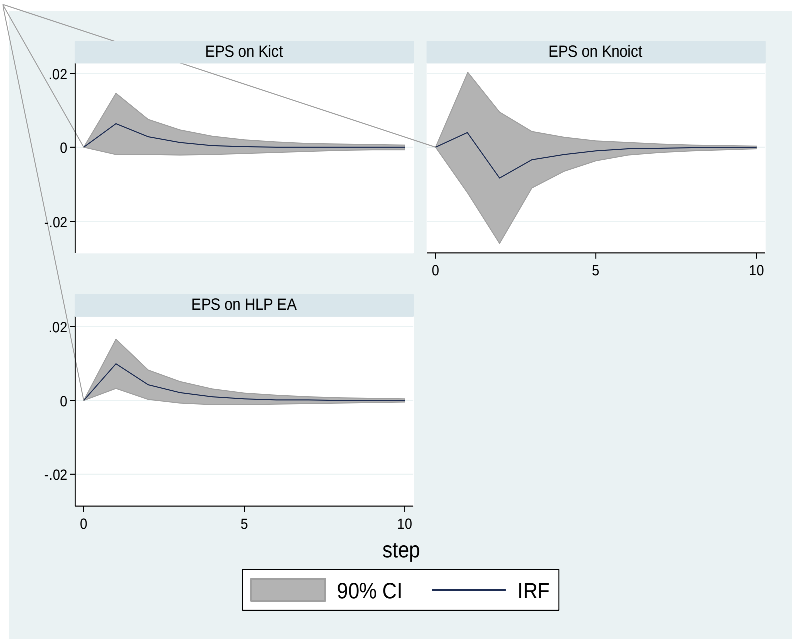


Figure A3 Response to a shock in EPS: MFP EA

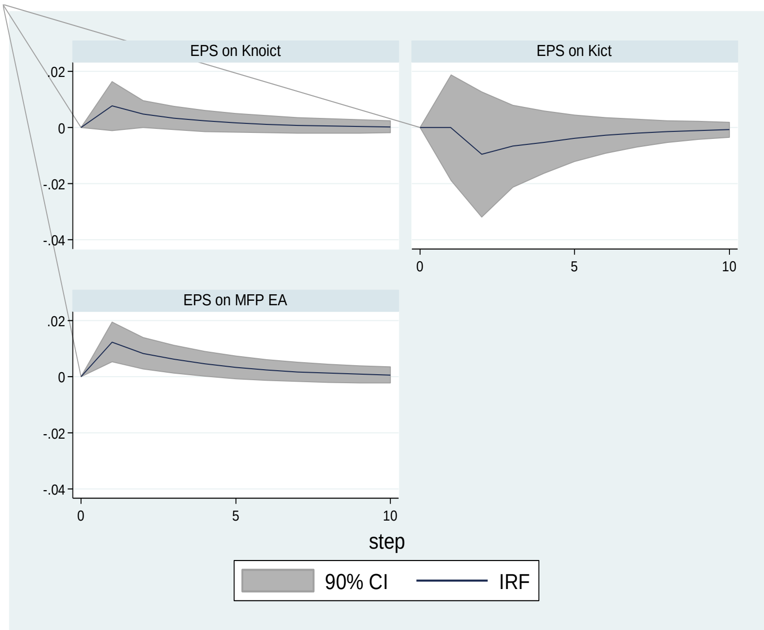


Figure A4 Response to a shock in EPS: HLP

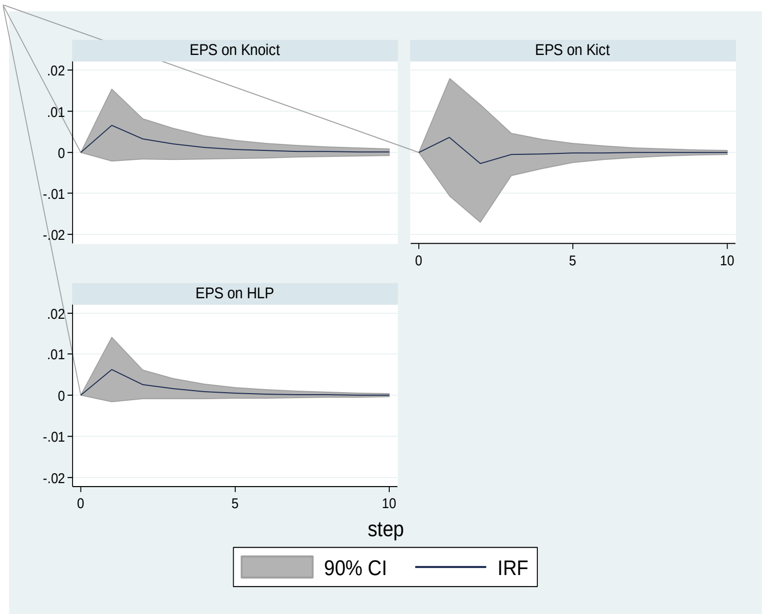


Figure A5 Response to a shock in EPS: MFP