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THE PRODUCTIVITY PUZZLE IN NETWORK INDUSTRIES: EVIDENCE FROM THE ENERGY SECTOR

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JEL Classification: D24, O47, H23

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What accounts for the recent widespread slowdown in the productivity in advanced economies has remained a puzzle. One plausible explanation has been attributable to regulation, particularly anti-competitive regulations and environmental regulations. This paper focuses on the regulated energy network sectors by undertaking three sets of analysis in examining TFP in a sample of OECD countries over the period 1995-2016. First, using the growth accounting method, we find that there is a substantial productivity puzzle for the electricity and gas sectors, which exhibits a lower TFP growth than the whole economy over the period, and falls post-financial crisis. Second, we identify the impact of regulation on productivity using a panel regression analysis. Our findings indicate that TFP levels seem weakly explained by changes to the competitive environment of the energy sector. Third, we show that energy and climate policy has negatively and significantly reduced energy sector productivity, at the same time as increasing capital input to the sector. We also find that the strength of energy and climate policy is positively correlated with lower aggregate TFP growth.

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1. Introduction

Increases in factor productivity is one of the most important sources of economic growth and rising living standards. During the last couple of decades, there has been increasing attention paid to the apparent productivity puzzle which relates to the phenomenon whereby productivity - total factor productivity (TFP) and labour productivity- in almost all advanced economies is flatlining (and in some cases, failing), after experiencing a long period of steady growth. This trend has become more evident since the Global Financial Crisis of 2008 since when the TFP performance of many OECD countries has been extremely poor. For instance, the current productivity slowdown – even before the impact of COVID-19 - in the UK has so far culminated in productivity being 19.7 per cent lower than the pre-2008 trend path in 2018 in the UK, which is almost double the previous worst productivity shortfall a decade after the beginning of a recession (Crafts and Mills, 2020).

The earlier occurrence of the productivity puzzle has produced a number of papers, with a particular spotlight being placed on Information and Communication Technologies (ICT) (see, e.g. Jorgenson and Stiroh, 2000; Oliner and Sichel, 2000, Jorgenson et al. 2006, Corrado, et al., 2007).[2] Some studies examine the impact of regulation and other competition enhancing policies on productivity growth (e.g. Nicoletti and Scarpetta, 2003). These provide evidence of a negative impact of the stringency of product market regulation on productivity growth in manufacturing industries, but not in services industries. Inklaar et al. (2008) focus on market services industries and find no effect of the average level of barriers to entry in services on productivity growth. While most network industries – such as electricity and gas - are in market services (Conway and Nicoletti, 2006), there is surprisingly no industry-level empirical study on these highly regulated industries which have witnessed significant regulatory reform to improve competition over the same period during which aggregate productivity has been slowing down. We attempt to fill this gap by focusing our study on the energy sector, more specifically the electricity and gas sectors[3].

Focusing on the energy sector suggests a further potential source of the productivity puzzle, namely climate related environmental policies. For instance, at the core of the European

[2] It could be that productivity growth was going to generally slow down as we hit diminishing returns to investment and hence there is no puzzle. However our analysis goes beyond this by analysing the differential impacts of policies between countries.

[3] Energy sector and electricity & gas sectors are used interchangeably throughout the paper.

Union's agenda is the decarbonsation of it economies, which has resulted in the formulation of legally binding climate change and energy targets among member states, with an emphasis on the renewable energy and energy efficiency targets, as well as the implementation of market-based environmental regulation on power plant installations such as the European Union Emissions Trading Scheme (EU ETS) which is the largest cap-and-trade system for carbon emissions worldwide (EC, 2012).

As a consequence, this sector is experiencing upward cost pressures which could affect its performance. Specifically, large amounts of capital have been pumped into energy sectors at a time when demand has been falling. The energy sector is also highly regulated in the United States, with private electric power companies in restructured states heavily regulated by government agencies on different aspects of their operations such as prices charged to customers, budgetary processes and energy efficiency programs (Hausman and Neufeld, 2011). There are also many federal, states and municipal level publicly owned utilities within a deregulated and liberalised market for power networks run directly by the government in some of these countries. To a lesser extent, the natural gas supply industry has exhibited many of the market reform trends experienced by the electricity sector (Pollitt, 2012).

Our paper follows the renewed interest in the productivity puzzle and offers a threefold contribution to the literature. First, we examine the productivity puzzle in the electricity and gas sectors by taking advantage of the new EU KLEM database which contains disaggregated energy sector data[4]. We explore the sector TFP growth trends, in a growth accounting framework, prior and after the global financial crisis, while paralleling this trend in the TFP growth patterns of the total economy for OECD countries. We also evaluate the contribution of inputs (capital and labour) to the growth of valued added. Second, we focus on examining the relationship between the level of TFP in the electricity and gas sectors and the degree of energy market reform and competition. We provide analysis based on sector-specific aggregate and dis-aggregated regulation indices. Third, we present an investigation of the effect of climate policies on the productivity level of the total economy and the energy sector. We analyse separately the impact of two types of climate policies: carbon pricing mechanisms and

[4] The latest release (November 2019) of the EU KLEM database run by the Vienna Institute for International Economic Studies (wiiw) contains data for the energy sector (electricity and gas) reported under code D. The previous EU KLEMS database releases (up to the 2018) have always aggregated data for the utilities sector (electricity, gas and water) and reported them together under code D-E. For the new EU KLEMS data release, see www. euklems.eu.

feed-in-tariffs for renewable energy. To our knowledge, this is the first attempt at identifying the relationship between climate policies and the level of TFP either at the economy level or in the energy sector.

Our findings confirm that a productivity puzzle does exist in the energy sector and in aggregate TFP growth, and we shed new light on the extent to which TFP levels in aggregate and in the energy sector are being held back by competition policy, regulatory reform and climate policy. Somewhat, unsurprisingly the productivity puzzle at the whole economy level in OECD countries would seem to at least be partly due to more ambitious environmental policy.

The remainder of the paper is structured as follows. Section 2 presents the literature review and Section 3 sets out the methodologies used in the paper. Section 4 describes the data we use and Section 5 discusses our results. Section 6 provides some conclusions and suggestions for further work.

2. Literature review

The existing literature in the growth accounting framework has provided numerous empirical studies which attempt to identify the contribution of inputs and productivity to the change in the growth performance in advanced economies. Much research based on growth accounting has stressed that investment in information and communication technology explain the United States growth surge (Jorgenson and Stiroh, 2000; Oliner and Sichel, 2000; Ferguson and Wascher, 2004; Jorgenson et al. 2006 and Corrado, et al., 2007). Far smaller productivity gains from ICT investment account for the lagging productivity in Europe, ostensibly due to the insufficient investment in ICT capital (Daveri, 2002; van Ark et al., 2002; Albers and Vijselaar, 2002 and van Ark and Jäger, 2017.) Studies on intercontinental comparison such as Gust and Marquez (2002) reveal that TFP growth decelerated in most Europeans countries as well as in Japan but United States, Finland, Sweden, Australia, and Canada experienced a positive TFP growth from 1995-2000. Exploring the productivity gap between Europe and the United States, van Ark, et al. (2008) show that United States accelerated in productivity growth from 1.2 percent in the 1973–1995 period to 2.3 percent from 1995 to 2006 while the continental European Union countries experienced a productivity growth slowdown from an annual rate of 2.4 percent to 1.5 percent between these two time periods. Although differences in total factor growth have been proposed to account for these divergent trend growth rates, most studies suggest that productivity differences have far more potential implications for per capita income differences across countries than differences in input accumulation.

However, these ICT explanations can be traced back to the role played by high level product market regulations, especially in the European regulated market services (Van Ark et al., 2008 and Miller & Atkinson, 2014). Conway et al. (2006), for instance, argue that the incentive to invest in ICT is stronger in countries and sectors characterized by lower regulation. As a result, more stringent product market regulation would be associated with lower TFP growth. Some evidence of this is provided by Crafts (2006), who shows that restrictive product market regulations, especially entry barriers, hinder technology transfer and have a negative impact on productivity; and links the past TFP improvement in the UK to the apparent low level of regulation relative to France and Germany. Barone and Cingano (2011) also suggest that lower regulation increases the growth rate of value-added and productivity of manufacturing industries in OECD countries, and find that the differential is about 0.7–1 percentage growth higher in low regulation country like Canada compared to France, which is considered a highly regulated country.

Focusing on the relative difference between regulated and unregulated sectors, Nicoletti and Scarpetta (2003) document a negative relationship between the stringency of product market regulation and TFP in the manufacturing industries. Specifically, they suggest that reduced entry barriers and private ownership are the two channels through which regulatory reform could enhance productivity gains in manufacturing, but find no such link in the regulated services industries. In the same vein, Inklaar et al. (2008) focuses on market services, averaged across industries, and find no effect of regulation on productivity growth. They provide further industry-specific evidence that regulations, particularly those limiting new entry, enhance productivity growth in regulated transport and storage services as well as post and telecommunications services, but not in other service industries. Bourles et al. (2013) provide compelling evidence that anticompetitive regulations in regulated upstream industries have curbed productivity growth of OECD downstream industries in the period spanning 1984-2007. However, Duso et al., (2019) fail to establish any significant direct effect of average regulation index on productivity level among the EU energy market firms.

Next to changes in product market regulations, the steady strengthening of climate change mitigation policies observed over the last quarter century constitutes another source of significant alteration to firms' and sectors' regulatory environment.[5] Due to the nature of their activity, network industries have been particularly exposed to these changes, having had to comply with a growing number of environmental regulations (Botta and Kozluk, 2014). While these were initially focused on the protection of the local environment, such as in the case of the U.S. SO_2 Program, recent years have witnessed the implementation and strengthening of legislation aiming at regulating global pollutants. Many OECD countries have introduced economy-wide or, more often, sector-level climate policies whose scope encompass the power and gas industries. In most countries, the power sector was among the first sectors to face climate change mitigation regulations.[6] Hence some of these regulations, such as carbon pricing, have now been in place for some time, allowing for an evaluation of their impact on the economy and the energy sector.

Much of the debate about the relationship between environmental regulation and firm performance dates back to the seminal work of Michael Porter (1991). Although *Porter's hypothesis* merely suggested a relationship between environmental regulation and firm-level innovation, later work has described its potential implications for firm performance. Palmer et al. (1995) and Jaffe and Palmer (1997) were among the first to describe such implications. In particular, they identify two interpretations of the hypothesis with opposite implications for firm performance. Under one interpretation ('*weak*'), environmental regulations impose additional constraints on firms' optimization problem and hence are expected to weigh negatively on their performance but hold the potential to stimulate certain kinds of innovation.[7] Under an alternative interpretation (*'strong'*), the introduction of new (and unexpected?) environmental regulation constitutes a shock that prompts firms to exploit previously unexploited profit opportunities while complying with the regulation. In this case, one expects environmental regulation to result in an improvement of firm performance.

[5] Such changes affect firms' production processes, resource reallocation, capital investment, labour intensity and innovation incentives (Albrizio et al., 2017). This, in turn, has the potential to affect the performance of firms, sectors, and economies.

[6] These policies were gradually extended/introduced in new sectors. For an up to date review of existing Renewable Energy Targets and Policies, see REN21 (2019). A more historical perspective is provided by the Climate Policy Database of the New Climate Institute, http://climatepolicydatabase.org/index.php/Climate_Policy_Database.

[7] As noted by Jaffe and Palmer (1997) themselves, this applies to firms that do not have a comparative advantage in environmental compliance or firms that invested in pollution abatement technologies prior to the introduction of environmental regulation. Such firms would most likely benefit from the regulatory change.

Porter's initial suggestion and subsequent discussions about its implications for firm innovation and performance stimulated substantial empirical work seeking to discuss it in a variety of institutional contexts. Studies investigating the 'strong' hypothesis focused on productivity (growth) whereas those exploring the weak hypothesis focused on innovation. Early studies focused primarily on the effect of local pollutant regulations, reflecting the policy developments of the time (Cohen and Tubb, 2015; Kozluk and Zipperer, 2014; Ambec et al., 2013). Most of these studies used sector-level data and, except for Albrizio et al. (2017), were focused on single context and have reached opposing conclusions.[8] That is, the evidence available from it does not allow a firm conclusion to be drawn as to the significance and direction of the effect of environmental regulation on firm productivity (growth). As noted in Ellis, Nachtigall and Venmans (2019), more recent studies have attempted to identify the effect of some climate policies on a number of firm/sector performance indicators. Among them, several focused on the relationship between carbon pricing and total factor productivity (Calligaris et al. (2018); Lundgren, 2015) in manufacturing sectors.

None of these studies, however, focused on the energy sector and virtually all of them investigated the role of the EU-ETS, with only one, Commins et al. (2015), focusing on carbon taxes. However one might expect that the energy sector itself is more likely to exhibit the 'weak' rather than the 'strong' Porter hypothesis given the fact that increasingly severe environmental regulations – especially with respect to measures to reduce energy consumption/output - have been directly applied to it. Energy sectors are likely to have more limited growth opportunities than non-energy sectors subject to environmental regulations.

One study to date, Albrizio et al. (2017), has included a wider range of climate policies in the scope of its investigation, using an environmental policy stringency index constructed by Botta and Kozluk (2014). In doing so, it attempts to get around the constraint posed by the lack of standardised cross-country proxies for the climate policies introduced. However, the focus is on overall policy stringency, which includes policies aimed at reducing emissions of both local and global pollutants and encompasses market and non-market based policies. In other words, their study does not allow to disentangle the effect of climate policies specifically.

[8] See Albrizio et al. (2017) for a review of these studies.

This paper adds to this earlier literature in at least three ways. First, its time coverage extends to years following the global financial crisis, when productivity puzzle is particularly apparent not only in Europe but across all developed economies. Second, it focuses specifically on a regulated sector, the energy sector. Most studies so far have focused on multi-industry analysis, especially covering the manufacturing sector which uses intermediate inputs from the regulated industries, and have generally attributed the slowdown in productivity to insufficient investment in ICT and document negative impact of regulation on TFP in the sector. Finally, this paper presents a first attempt at investigating the effect of climate policies on the productivity level of the total economy and the energy sector.

3. Methodology

We follow the standard growth accounting method which measures the growth of outputs (i.e. GDP, value added - VA) that are explained by the growth of different inputs (such as labour, capital and intermediate inputs) and by an unaccounted or unexplained growth (known as residual)[9] which represents the productivity growth. Theories about growth accounting methods and applications have evolved over time with some key influential studies from Abramovitz (1956), Solow (1957), Kendrick (1961), Jorgenson and Griliches (1967) and Jorgenson et al. (1987).

The methodology we have used for estimating the TFP growth figures is based on Jorgenson et al. (1987), in line with the one used by EU KLEMS[10] project (Timmer et al., 2007, Stehrer, et al., 2019). The production function for industry *i* can be written as follows:

$$Y_{i=} fi \ (Ki, Li, Mi, T) \qquad (1)$$

Where Y is output, K is capital services, L is labour services, M is intermediate inputs (purchases from other industries), T accounts for technology indexed by time. Based on the assumption of constant return to scale and competitive markets[11], the growth of industry level can be expressed as[12]:

[9] This is also referred as a measure of ignorance", Abramovitz (1956).

[10] EU KLEMS stands EU level analysis for capital (K), labour (L), energy (E), materials (M) and service (S) and the, and the US. For the latest update of the EU KLEMS data, see www. euklems.eu.

[11] This means that the value of output is equal to the values of all inputs then $P^Y Y = P^K K + P^L L$, where P^Y, P^K, P^L denote the prices of output, capital and labour.

[12] The decomposition made in Equation 2 is the basis of growth accounting results in the EU KLEMS database.

$$\Delta lnY_t = \tilde{v}^M \Delta lnM + \tilde{v}^K \Delta lnK + \tilde{v}^L \Delta lnL + \Delta lnA \quad (2)$$

Where Δ denotes changes between periods $(t, t+1)$, $\tilde{v}$ represents two period average of the share of the input related to the nominal value of output given by Eq. 3, and A the TFP.

$$v^M = \frac{P^M M}{P^y Y}; \quad v^L = \frac{P^L L}{P^y Y}; \quad v^K = \frac{P^K K}{P^y Y} \quad (3)$$

In addition, the assumption of constant return to scale means that $v^M + v^L + v^K = 1$ which allows the estimation of TFP growth (ΔlnA) based on the share of the observed inputs.

The component ΔlnY_t from Equation 2, refers to the change of output growth, however a more restricted measure, such as the value added (VA) can be estimated using the same equation. In this case, only capital inputs and labour inputs are taken into account[13]. Based on Equation 1, value added can be represented as follows:

$$VA_{i\,=}\; f^i\,(K_i, L_i, T) \quad (4)$$

Then in agreement with Equation 2, Equation 4 can be denoted as follows:

$$\Delta lnVA_t = \bar{e}^K \Delta lnK + \bar{e}^L \Delta lnL + \Delta lnA$$
(5)

Where $\bar{e}^L = \frac{P^L L}{P^{va} VA}$, $\bar{e}^K = \frac{P^K K}{P^{va} VA}$ (6)

Applying the constant return to scale which means that $\bar{e}^K + \bar{e}^L = 1$, Equation 5 can be written as:

[13] This is explained by the fact that $Gross\ Ouput\ (GO) = Value\ Added\ (VA) + Intermediate\ Inputs\ (II)$. Then the component that reflects the share of intermediate inputs in Equation 2 is not included.

$\Delta lnVA_t = \bar{e}^K \Delta lnK + (1 - \bar{e}^K)\Delta lnL + \Delta lnA$

(7)

The TFP growth estimations and discussion in this study are based on value added instead of gross output which means that intermediate inputs have been excluded from the TFP analysis[14]. Results from the two methods are different[15], and those results from value added TFP growth are usually higher than those from gross output based TFP growth (van der Wiel, 1999, Oulton, 2000). Both methods have pros and cons and the selection of one or another method may depend on the purpose of the productivity measure (OECD, 2001).

In the second and third empirical sections of this study, we employ econometric panel regression while building on related empirical literature that links regulatory indices and climate policy with economic outcomes. To better reveal the determinants of productivity, we regress total factor productivity on market regulation indicators and a set of macro variables which capture some cross-country differences in the second analysis. We also specify the same model for relationship between productivity and climate policies. To mitigate the potential endogeneity problems we lag all explanatory variables one year, which we do throughout our regressions for all variables[16]. The equation that we estimate is thus.

$$Y_{it} = \beta Z_{it-1} + \gamma X_{it-1} + \eta_{it} + \psi_{it} + \varepsilon_{it} \quad (8)$$

where Y_{it} is total factor productivity level country *i*, in year *t*, Z_{it-1} denotes either product market regulatory indicators measured by the OECD regulatory index (aggregate index, entry barriers, public ownership, vertical integration, market structure) or climate policies such as price and non-price policies. X_{it-1} is vector of country-specific macro variables (GDP per capita, energy consumption, energy import and renewable capacity), η_{it} is unobserved time-invariant country-specific fixed effects, ψ_{it} is time fixed effect and ε_{it} is the idiosyncratic error term.

[14] One of the main reasons is due to the lack of information of GO variables from the latest EU KLEMS data base.

[15] According to Cobbold (2003, p.23): *"The gross output method is intended to measure disembodied technological change whereas the value-added based measure reflects an industry's capacity to translate technical change into income and into a contribution*".

[16] This approach is a based on the assumption that the lagged values of the policy are uncorrelated with the error terms of the regression equation. For application of this approach on TFP growth analysis, see Buccirossi et al., 2013; Bourlès, et al., 2013; Duso et al., 2019 and Griffith et al., 2004.

4. Data description

In this study of productivity puzzle in network industries, we employ three categories of dataset. The first set of dataset comes from the new EU KLEMS Growth and Productivity Accounts based on the November 2019 release of the EU KLEMS database. This database is run by the Vienna Institute for International Economic Studies (wiiw) which incorporates the latest EU KLEMS update and financed by the European Commission. The latest database series covers measures of output, inputs and TFP growth at the industry level for all European Union member states, Japan and the United States. The statistical database component contains growth accounts and national accounts files. To build a sector level dataset for our study, we consider network industries - i.e. electricity & gas - and total economy for the period 1995-2016 across 13 countries[17]. The growth accounts file of the EU KLEMS database offers information in percentage points about TFP growth data and also contains more granular industry-level measures of the growth of skill distribution of the labour force and a detailed capital input growth decomposition. Labour input growth reflects not only changes in hours worked, but also changes in labour composition in terms of socioeconomic dimension across time. Capital input growth is decomposed into five components of which two are tangible capital services — tangible information and communications capital (ICT) capital and tangible non-information and communications capital (non-ICT)—and three are intangible capital services— intangible research & development (R&D), intangible software and database (SoftDB) and intangible other intellectual property products (OIPP).

The second category of dataset used in this study comes from data on regulatory reform variables taken from the OECD from the Product Market Regulation indicators, which are the indicators of regulation in energy, transport, and communication (ETCR). They represent the milestones in the gradual but progressive restructuring of regulated industries and are widely used database to measure the effect of regulation on market outcomes (e.g. Alesina et al., 2005; Duso and Seldeslachts, 2011; Bourlès et al., 2013; Duso et al, 2019)[18]. We rely on regulatory reform variables of the energy sectors (electricity and gas sectors), with regulation indicators

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[17] Due to the limited times series of the growth accounting data for some countries, we only focus on 13 countries which have sufficient data that allows for meaningful comparison across the pre-and- post financial crisis period. The 13 countries considered in the growth accounting section of the study are Austria, Belgium, Denmark, Finland, France, Germany, Italy, Japan, Netherland, Sweden, United Kingdom and United States.

[18] Although these papers do not cover the recent regulatory reform undertaken by the countries, there is a 2018 update of the Product Regulatory Market data which reflect the current situation in these OECD countries, but this version only reports the aggregate index and do not contain the sub-indicator indices.

covering aggregate index as well as sub-indicators which use categorical variables as a measure of the degree of public ownership, vertical integration, entry regulation and market structure of national energy industries in our 22 sample countries[19] from 1995-2013[20]. These indicators range from 0 to 6, with 0 representing the fully open market in which entry barriers, public ownership, vertical integration and market structure are minimised and a score of 6 is given to a closed market with the most restriction to competition. The OECD expresses the energy market indicators for the variables as follows, a "public ownership", ranging from 0 (full private ownership in the production/import, transmission and supply phases) to 6 (public ownership for all), the variable "vertical integration", ranging from 0 (vertical separation in all phases) to 6 (vertical integration for all), the variable "entry regulation", which is a weighted average of legal conditions of entry in a market and is coded from 0 (free entry) to 6 (franchised to one firm), and the variable market structure, coded from 0 (no firm has a market share above 50% in either the production/import, transmission or supply phase) to 6 (the same firm has a share above 90% for each phase)[21]. Conway and Nicoletti (2006) point out that these variables are directly associated to underlying policies and as such are largely viewed as exogenous to productivity developments.

We explore the impact of these variables on the level of TFP used for the econometric analysis. We also obtained data on industry-specific real capital stock, proxied by real gross fixed capital formation, expressed in national currencies at 2010 prices and publicly available in the capital data file of the EU KLEM database to estimate TFP using production function approach proposed by Levisohn and Petrin (2003). Data on gross value added, labour and material, proxied by intermediate input, are sourced from national accounts file of the EU KLEMS database. Labour is expressed in thousand number of persons employed, gross value added and

[19] The second and third empirical sections of the paper extend the sample countries due to the availability of a more detailed data across these countries on labour, capital stock and intermediate input which enable us to estimate the level of total factor productivity instead of using TFP growth which is limited in data coverage.

[20] The ETCR dataset provides an annual time series from 1975 but the version of OECD Product Market Regulatory data containing both the aggregate indicator and the sub-indicators is not available beyond 2013. Hence, we used data from 1995-2013 as the EU KLEMS data starts from 1995. The Aggregate index is a composite regulatory indicator of energy markets at the member state measured as an average of four sub-indicators i.e. entry barriers, public ownership, vertical integration and market structure over electricity and natural gas sectors. To confirm our findings, we carried out further analysis using the aggregate index in the latest version of the OECD Product Regulatory Market and the results of the regulatory index are quantitively similar in term of magnitude and the extent of significance of the estimated coefficients as reported in Table A6 of the appendix.

[21] For more details, see Conway and Nicoletti (2006).

material are expressed in millions of national currencies at current prices and are deflated using the corresponding sectors price index of gross value added (2010 = 100). The real gross value added, real capital stock and real material in national currencies are then converted to dollars (US$) using the exchange rate from the Penn World Tables (PWT9.1). Besides the regulatory variables and the standard variables of TFP level production function estimation, we added some macro variables such as GDP per capita obtained from the World Bank to account for institutional differences across these sample countries. Other macro variables included are electricity consumption, energy import as a share of total energy consumption and net renewable total capacity. These data are provided by the International Energy Agency (IEA) through the UK data service (IEA, 2019a, 2019b, 2019c).

The last category of data comprises variables capturing the stringency of two types of climate policies: carbon pricing and Feed-in-Tariffs (FiTs). The economy-wide and sector-level carbon price data used in the models estimated below is constructed based on a dataset of sector-fuel level carbon prices (see Dolphin et al., 2020). Both the economy-wide and energy sector carbon prices are constructed as emissions-weighted averages of these sector-fuel level carbon prices and expressed in 2015USD/tCO2e. The economy level price therefore is an average of prices introduced in all sectors of the economy whereas the [energy sector] price reflects the average price across fuel types within that sector. This approach follows the methodology described in Dolphin et al. (2020). The stringency of Feed-in-Tariff policies is captured by stringency indices provided by the OECD (see Botta and Kozluk, 2014).

5. Results & Discussion

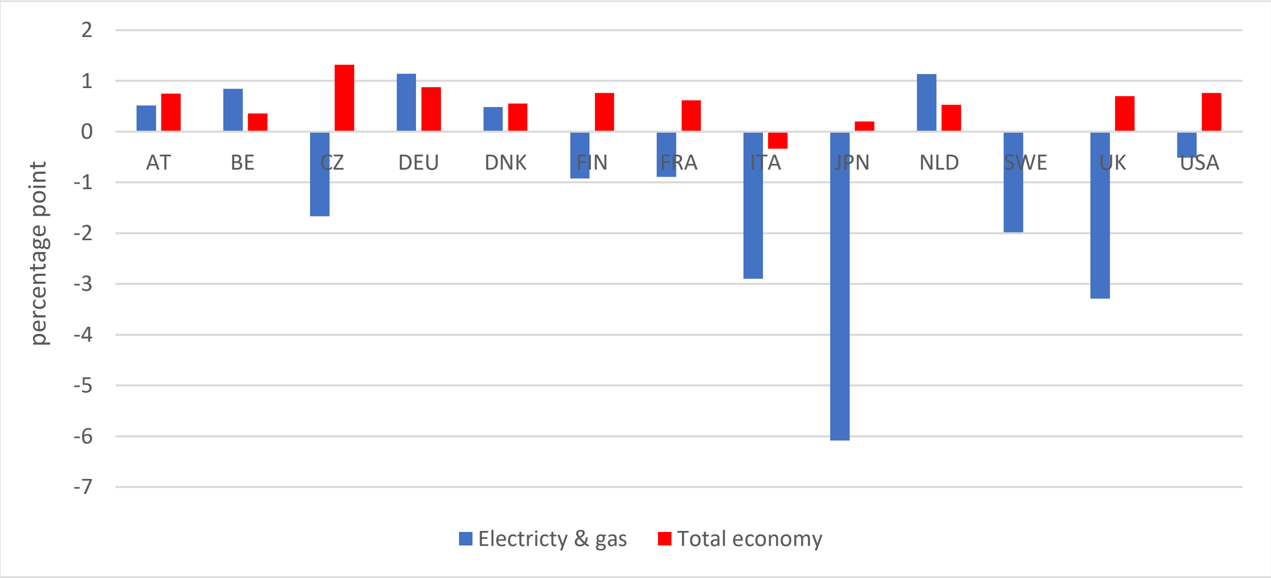
5.1. Growth accounting analysis

To facilitate comparisons of total factor productivity (TFP) in the network industries, we focus our statistical analysis on the electricity and gas sector, and contrast these sectors with total economy. The analytical period spans 1998-2016 across 13 sample countries using the growth accounting data from the EU KLEMS database[22]. Figure. 1 shows the results of the TFP growth, which reflects the portion of gross value added growth not attributed to the factor inputs, over the sample period. With Italy being an exception, TFP growth had a positive contribution to the value added growth of the total economy during this entire time period.

[22] We annualized data to account for the fact that years of data coverage differ across countries. For example, there is no data for Japan in 2016.

However, TFP growth for the electricity and gas sectors experienced a considerable negative growth, particularly for countries such as Japan, United Kingdom, Italy, Sweden, Czech Republic, United States, France and Finland. Although countries such as Germany, the Netherlands, Denmark, Austria and Belgium witnessed a positive TFP growth during the period. Overall, Germany experienced the largest average growth rates in electricity and gas sectors (1.1% p.a.), while Japan recorded, by wide margin, the least productivity growth of -6.1% p.a. Czech Republic has the highest average productivity growth in the total economy (1.3% p.a.).

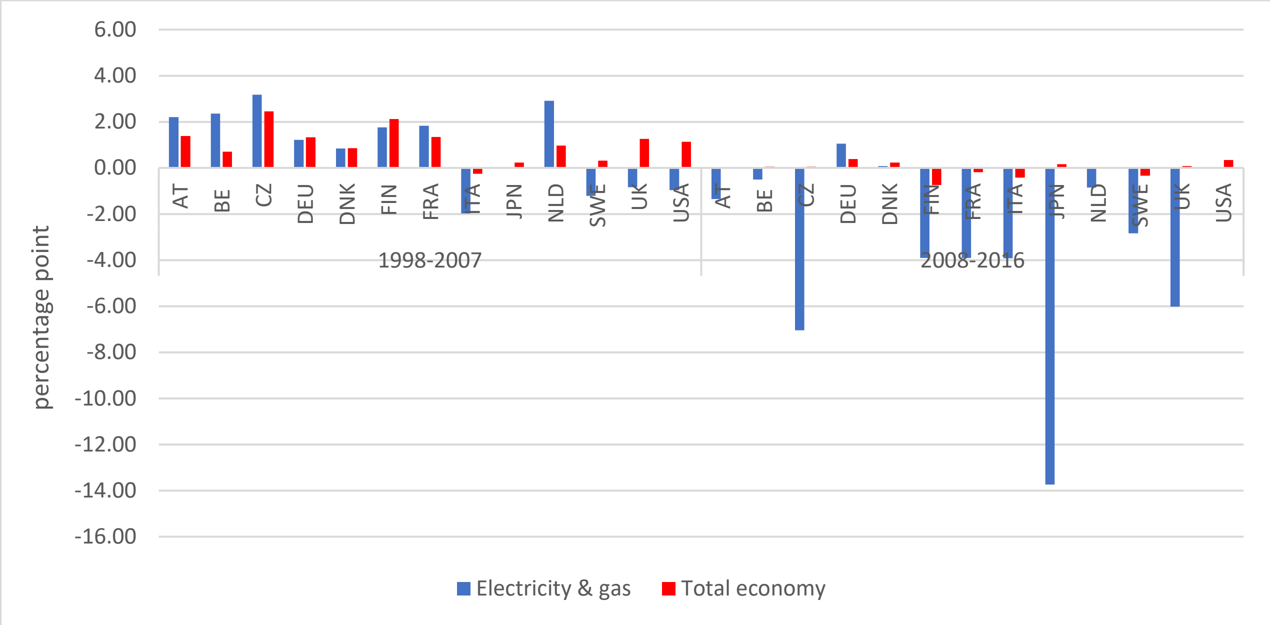
Figure 1: Total Factor Productivity Growth, 1998-2016



Source: EU KLEMS DATABASE, 2019.

We disentangle the TFP growth results into two time periods (1998-2007 and 2008-2016) as shown in Figure 2. i.e. pre-and-post global financial crisis era, in order to gain more insights into the structural break occasioned by the crisis on total factor productivity growth. There appears to be a substantial diversity of TFP growth among countries before and after the global financial crisis. Looking at the TFP growth in the electricity and gas sectors, the negative TFP growth of Japan is particularly striking as the country experienced the largest negative growth in TFP growth among the sample countries, averaging -13.7% p.a., in the period after the crisis despite maintaining a near-zero TFP growth before the crisis. This dismal TFP growth performance in the Japanese electricity and gas sector is not surprising against the backdrop of the earthquake at the Fukushima Daiichi power plant in March 2011, which led to the closure of many nuclear plants and resulted in a considerable loss of electricity production, physical and human capital (Rafindadi & Ozturk, 2016). This event singlehandedly caused a steep TFP decline in the electricity and gas sector amounting to an annual productivity growth of -30% p.a. and -61% p.a. in 2011 and 2012 respectively[23].

Figure 2: Total Factor Productivity Growth, Pre and Post Financial Crisis



Source: EU KLEMS DATABASE, 2019.

The productivity growth in the UK has been lacklustre in the electricity and gas sectors with an average annual TFP growth of -0.8% p.a. observed before the 2008 crisis. The average annual negative productivity growth widened amid tepid productivity performance following the crisis, amounting to -6.0% p.a. in the electricity and gas sectors. It is also interesting to note that Italy recorded the largest negative growth in TFP of about -1.97% p.a. before the crisis, and this trend became exacerbated afterwards, culminating in a TFP growth rate of -3.92% p.a. This finding reinforces Italy's economic situation as one of the worst performing economies in Europe. This is consistent with Morsy and Sgherri (2010) who posit that the financial crisis was expected to have a long-lasting impact on Italy's economy and the negative TFP growth trajectory was highlighted to have been caused by resource misallocation (Hassan and Ottaviano, 2013).

[23] See Figure A1 in the Appendix for TFP growth by country across years in the electricity and gas sector.

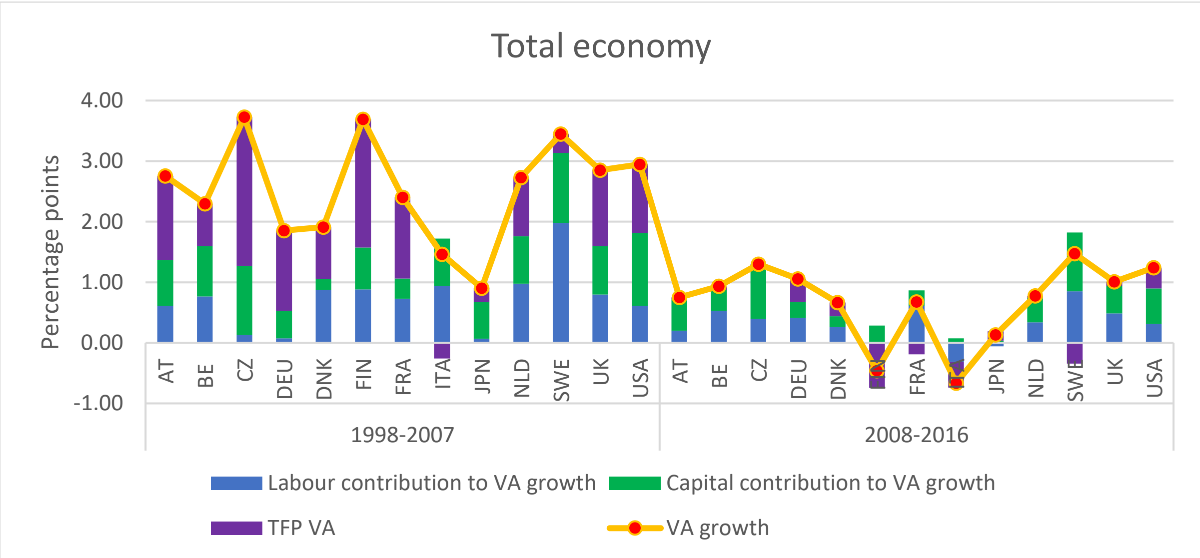
In the case of France, a positive average annual TFP growth was observed before the crisis in the electricity and gas sectors, and total economy. However, their growth trend became negative after the crisis, with the electricity and gas sectors having the highest productivity decline (-3.9% p.a.). This post-crisis development in electricity and gas sectors is also true for most European countries; e.g. Finland (-3.9% p.a.), with a much stronger decline for Czech Republic (-7.4% p.a.), and a moderate decline for Sweden (-2.8% p.a.), Austria (-1.5% p.a.), Netherland (-0.9% p.a.) and Belgium (-0.5% p.a.). On the contrary, only Germany maintained an appreciable positive TFP growth of 1.1% after the crisis in its electricity and gas sector, although the productivity growth was marginally lower than its pre-crisis growth of 1.2% p.a.

Indeed, despite the 2001 dotcom crisis and the financial crisis in 2008, the United States did not experience a negative productivity growth in the total economy in the two time periods. However, the productivity growth of the electricity and gas sectors was negative (-0.96% p.a.), perhaps due to the mix of factors such as higher prices in restructured states (Borenstein and Bushnell, 2015) and California's electricity crisis (Kwoka, 2008) that brought about the suspension of further electricity restructuring that could enhanced efficiency in the sector in most states. Of course, the later period saw a moderate improvement in the sectors with an average annual productivity growth of 0.02% p.a, arguably due to improved drilling techniques and increased well productivity in shale gas production (see Ikonnikova & Gülen, 2015; Montgomery & O'Sullivan, 2017).

There has been a big debate over the sources of the post-crisis slowdown in global value added growth. There are usually two widely believed arguments for this development; one that it is traceable to a notable shortfall in capital investment, while others point to the flattening productivity witnessed currently. Therefore, dimensioning the growth rate of valued added into different components can reveal the major sources of growth. Thus, we decompose the value added growth into TFP growth, labour input growth and capital input growth in order to assess the contribution of productivity growth vis-a-visa input growth contribution to value added growth.

Figures 3a and 3b plot the growth contributions of factor inputs and TFP to value added growth for the total economy and electricity & gas sectors respectively. A cursory look at the figures reveals that TFP growth is the major driver of slower growth in the post-crisis period. In the case of total economy, Figure 3a shows that while Germany growth of value added slowed from 1.9% p.a. on average per year in the period 1998-2007 to 1.1% p.a. in the period 2008-2016, the UK growth slowed substantially more from 2.9% p.a. in the period 1998-2007 to only 1.0% p.a. in the period. Nevertheless, capital input growth has remained a positive driver of growth in both periods for the some of the countries, especially the United Kingdom and Sweden where the rapid TFP growth in the pre-crisis period has been significantly depleted and has not witnessed any appreciable improvement since 2008, reflecting the weak total economy value added growth in the post-crisis period. Hence, we find evidence that is really more striking between value added growth and TFP growth than with factor inputs growth. Thus, given the tanking global macroeconomic growth, the rapid slowdown the TFP growth represents a serious concern to the electricity and gas sector, and total economy of the sample countries.

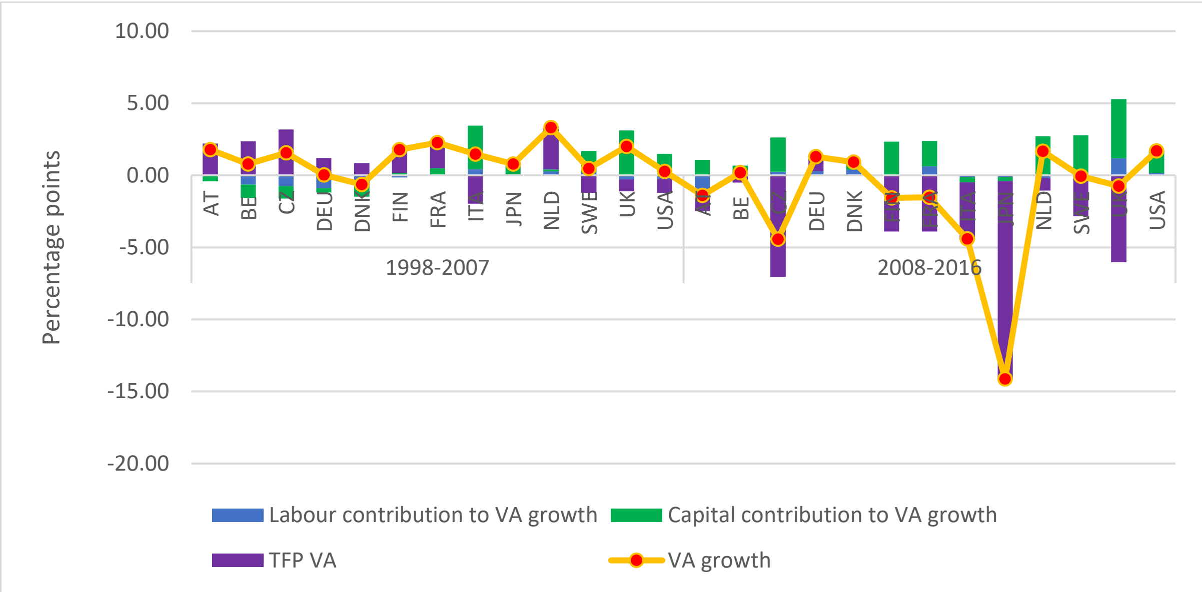
Figure 3a: Contributions to Growth of Value Added in Total Economy



Source: EU KLEMS DATABASE, 2019.

In the case of in the electricity and gas sectors as shown in Figure 3b, the growth rate of value added fell markedly in the period following the financial crisis, and this is engendered mainly by dwindling productivity growth, with an abrupt dip in Japan. While the share of capital input growth in the value added growth increased significantly in post-crisis period, especially in the United Kingdom, Finland, France and the Netherlands, it is astonishing to observe that the accumulation of capital input could not offset the negative trajectory in value added growth. For instance, whereas capital growth in the United Kingdom increased by almost a full percentage point from 3.1% p.a. from 1998-2007 to 4.1% p.a. from 2008-2016, the valued added growth declined from 2% to 0.7% between these two periods. What's more, a substantial rebound in value added growth relative to pre-crisis growth in was recorded in Germany, including Denmark and United States. Although, average annual productivity growth of 1.7% p.a. in the United States was still slightly higher than Germany (1.3 % p.a.) and Denmark (0.9% p.a.) in 2008-2016. Thus, the reduced TFP growth rate is therefore a major drag in the electricity and gas sectors.

Figure 3b: Contributions to Growth of Value Added in Electricity &Gas sectors



Source: EU KLEMS DATABASE, 2019.

The slowdown in TFP growth in the electricity and gas sectors might also be caused by number of factors, many of them attributable to a set of global and regional (European) directives, and member states develop and maintain national programmes to meet those directives. For example, the EU emission directives prompted the 2050 decarbonisation targets by the UK government, which is a set a long-term GHG reduction target of 80% by 2050 compared to 1990 levels[24]. This has important implications for productivity growth as these policies are anchored on the underlying objectives of promoting resource use efficiency and generation of low carbon technologies. More specifically, the national energy sector reforms in favour of the European energy transition programme might be associated with substantial increases in capital cost due to the addition of renewables and increased interconnection and lower demand as a result of increased energy efficiency (which itself might add capital costs). Meanwhile

[24] For a discussion on UK decarbonisation pathways, See Pye et al. (2015).

increased renewable generation displaces fossil fuel plants and lowers wholesale prices. This implies higher input costs at time of lower revenues and hence lower measured TFP growth.

5.1.1. *Simple correlation*

The results of the descriptive analysis show important variation in the growth contribution of factor inputs and TFP to value added growth. We carry out a pairwise correlation analysis to reveal the degree of variation of these growth contributions. The simple correlation of the growth contributions of factor inputs and productivity for total economy is reported in Table 1. Both TFP and labour input growth have a positive and statistically significant correlation with value added growth, at 87% and 69% respectively, while capital input growth is fairly correlated with value added growth at about 40%. The correlation coefficient of TFP growth reinforces our earlier findings that TFP growth is the major driver of value added growth. Thus, it appears that slow-growing countries in terms of value added growth are associated with a lower TFP growth in the whole sample period.

Table 1: Growth of Inputs, TFP & VA correlation for total economy, 1998-2016

	TFP growth	Labour input growth	Capital input growth	Value added growth
TFP growth	1			
Labour input growth	0.2923***	1		
Capital input growth	0.1233*	0.3300***	1	
Value added growth	0.8737***	0.6882***	0.3965***	1

Tables 2 reports the correlation of growth contributions in the electricity and gas sectors. We also observe that TFP growth is highly correlated with valued added growth. However, labour input growth have weak but significant correlation with value added growth and capital input growth is not significantly correlated with value added growth. Strikingly, the findings reveal another difference in the correlation between TFP growth and factor input growth. While TFP growth is negatively correlated with capital and labour input growth in electricity and gas sectors, the correlation of TFP growth with input growth is positive in the total economy. These correlations are all the more reassuring in that the whole economy behaves as we might expect while electricity and gas sectors are different.

Table 2: Growth Inputs, TFP & VA correlation for electricity and gas sectors, 1998-2016

	TFP growth	Labour input growth	Capital input growth	Value added growth

TFP growth	1			
Labour input growth	-0.2218***	1		
Capital input growth	-0.2312***	0.1487**	1	
Value added growth	0.9601***	-0.0440	0.0074	1

Furthermore, Table 3 reports the correlation of TFP growth among electricity & gas sector, and total economy. This reveals that electricity and gas sector TFP growth has a weak but significant correlation with total economy's TFP growth, underscoring the supposition that productivity growth in the electricity & gas sector has a tendency to behave differently from the total economy.

Table 3: Electricity & Gas, and Total economy TFP growth correlation

	Electricity & Gas	*Total economy*
Electricity & Gas	1	
Total economy	0.1817***	1

To further illustrate the TFP slowdown arising from the post-global financial crisis, we turn to price data in order to examine whether productivity growth is driven by price effect i.e. if the change in price index as observed in the implicit price deflator measured in national currencies reflects any increase in productivity growth, as well as in value added growth. Looking at the correlation results, Tables 4-5 show that the price index growth is inversely correlated with productivity growth for the electricity and gas sectors, and the total economy. This negative relationship also is revealed in the correlation between the price index growth and the growth rate of value added. This is quite interesting as this suggests that a decrease in price occasioned by falling costs of inputs is associated with increasing productivity growth in the electricity and gas sectors, and total economy.

Table 4: TFP, Value Added & Price Indices Correlation- Total Economy, 1998-2016

	TFP growth	*Growth rate of value added*	*Price_Index growth*
TFP growth	1		
Growth rate of value added	0.8737***	1	
Price Index growth	-0.2247***	-0.3257***	1

Table 5: TFP, Value Added & Price Indices Correlation- Electricity & Gas Sector, 1998-2016

	TFP growth	*Growth rate of value added*	*Price_Index growth*
TFP growth	1		
Growth rate of value added	0.9601***	1	
Price Index growth	-0.2514***	-0.2116***	1

The extent of the contribution of different dimensions of capital such as tangible assets (ICT capital and non-ICT capital) and intangible (research & development, software and database and other intellectual property products) to capital input growth was also examined. Tables A3 shows that all capital input components i.e. both tangible and intangible capital are significantly associated with capital input growth in the total economy. Table A4 reports that only tangible capital input growth is positively and significantly associated with overall capital input growth, while intangible capital growth is not significantly correlated with overall capital input growth in electricity and gas sector[25].

Furthermore, we attempt to examine the past behavioural patterns of factor input growth and TFP growth in relation to gross value added growth by looking at historical data, especially the period that is not covered by our sample. Although, Tenreyro (2018) argues that the productivity growth slowdown seems be more pronounced in the UK following the post-crisis period relative to what has been experienced by other developed countries, much less emphasized is whether this experience is symptomatic of the past growth contribution or due to quality of factor inputs. Hence, we delink the growth contributions to value added growth in the total economy by splitting our data into pre-sample and sample period using the UK time series from 1970 to 2016. In the pre-sample period between 1970 and 1997, Table 6 reports the correlation results which show a positive relationship between TFP growth and value added growth while capital input growth has no significant relationship with value added growth.

Table 6: UK Market Sector Correlation, Pre-Sample Period 1970-1998

	TFP growth	Labour contribution	Capital Contribution	Value added growth
TFP growth	1			
Labour contribution	0.1212	1		
Capital Contribution	-0.3805*	0.2001	1	
Value added growth	0.7667***	0.7207***	-0.0366	1

[25] Tables A3-A5 are reported in the appendix

However, in the sample period between 1998 and 2016, Table 7 reports the correlation results which confirm a significant positive relationship between value added growth with capital input growth, albeit with a stronger positive relationship with TFP growth. Thus, the contemporary period points to an increasing role of capital deepening as a significant source of the valued added growth relative to the pre-sample period. This finding reinforces the UK productivity puzzle narrative that despite the fact that the U.K. economy was building sufficient intangibles capital post-2000, the slowdown in aggregate economy productivity still remains (Marrano et al., 2009).

Table 7: UK Market Sector Correlation, Sample Period 1998-2016.

	TFP growth	Labour contribution	Capital Contribution	Value added growth
TFP growth	1			
Labour contribution	0.3464	1		
Capital Contribution	0.4225*	0.0662	1	
Value added growth	0.9210***	0.6435***	0.5211**	1

5.2. *Productivity and regulation*

Shedding further empirical light on the productivity puzzle following the global financial crisis, we observe that the rate of log total factor productivity is persistently slowing down in all the countries in our sample as shown in Figure. 4. We consider the relevance of regulation of the network industries, especially the wave of regulatory reform in energy markets, in our investigation of the productivity puzzle. Although regulation of network industries has huge economic, social and political importance, more often than not, regulation is usually associated with inherent trade-offs between economic and societal

Furthermore, insights drawn from analyses of the regulation has pointed out potential unintended consequences of regulatory reforms. For example, Brau et al. (2010) posit that heavily regulated markets may have negative welfare effects since public ownership, vertical integration and market entry regulation distort the allocation of resources among sectors and firms, thereby weakening the overall economic performance. The costs faced by existing firms face when expanding their productive capacity can also influence regulation (Alesina, et al., 2005). Hence, we hypothesize that negative effect of regulation on the energy industries can be linked to the productivity puzzle. Therefore, using a panel of OECD dataset on product market regulation covering a sample of 22 countries from 1995-2017, we examine whether and how various dimensions of product market regulation influences have affected the rate of log total factor productivity in the electricity and gas industries[26].

Table 8 presents the results for the productivity impact of aggregate indicators and sub-indicators for the energy industry. Looking at column 1, we find that the coefficient of the aggregate regulatory indicator has a negative effect on TFP, albeit weakly statistically different from zero. One plausible explanation is that not all the individual sub-indicators which are components of the aggregate indicator show a statistically significant relationship with productivity as reported in column 2. Nevertheless, the result is similar to the EU-wide energy firms study by Duso et al. (2019) who find a negative but not statistically significant relationship between the aggregate regulatory indicator and TFP. However, in column (2), there is strong evidence supporting our hypothesis that entry barrier regulation influences TFP. The estimated coefficient suggests that increased entry barriers, which reflect a degree of restriction in the opening of the energy market to new entrants, reduces productivity. This is also consistent with Nicoletti and Scarpetta (2003) , Craft (2006) and Buccirossi et al. (2013) who find that entry barriers to competition has a negative effect on productivity growth. Nicoletti and Scarpetta (2003) argue that increased entry barriers slows down the adoption of existing technologies, largely due to reduction in competitive pressures and the technology spillovers necessary for increasing productivity.

[26]We estimate total factor productivity of country *i*, in year *t* as the residual of a country-specific translog production function, using Levinsohn and Petrin (2003) approach.

Table 8: The impact of regulation on total factor productivity level for the electricity and gas sector

Variable	lnTFP (1)	lnTFP (2)
Aggregate regulation index$_{t-1}$	-0.0355*	
	(0.0213)	
Entry barriers index$_{t-1}$		-0.0679***
		(0.0140)
Public ownership index$_{t-1}$		0.0621***
		(0.0226)
Vertical integration index$_{t-1}$		0.0383
		(0.0304)
Market structure index$_{t-1}$		0.0158
		(0.0183)
GDP per capita$_{t-1}$	0.153	0.161
	(0.175)	(0.210)
Energy consumption$_{t-1}$	-0.902***	-0.123
	(0.205)	(0.325)
Energy imports$_{t-1}$	-0.00128***	-0.000861**
	(0.000390)	(0.000394)
Renewable capacity$_{t-1}$	-0.104***	-0.149***
	(0.0240)	(0.0270)
Post financial crisis$_{t-1}$	-0.494***	-0.461***
	(0.0935)	(0.108)
Constant	1.880	-1.035
	(1.564)	(1.947)
Observations	375	300
R-squared	0.469	0.526
Country FE	YES	YES
Year FE	YES	YES

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

We find a robust evidence that increased public ownership increases the productivity level. While this finding is congruous with Nicoletti and Scarpetta (2003) who confirm the positive productivity effect of state control, it runs contrary to the commonly held view in the literature that state-owned energy utilities have a mixed range of objectives that can lead to lower incentives and competitive pressures which are likely to encourage innovation and the adoption of productivity enhancing improvements. This seemingly contradictory finding may be explained by the fact that various models of energy liberalization exist in different countries. In effect, the government can become an equity holder in a regulated utility. For instance, Ajayi et al. (2017) reveal that there exists a mixed public-private ownership within the deregulated and liberalised markets in Scandinavian countries, as well as in a deregulated and partly privatized market in Germany, which are behaving competitively in the market. As matter of fact, Brau et al., (2010) argue that Denmark, under public ownership until recent years, had consumer gas prices below the EU average in most years which signals some high degree of competition expected to increase productivity. However, the estimates of the coefficient of vertical integration and market structure do not show any impact on productivity.

Turning to the impact of macro variables, the estimates of the coefficient of GDP per capita also does not indicate any robust impact on productivity, which contradicts our expectation that more industrialized economies should experience a rise in their TFP level. Meanwhile, energy consumption appears to have played the most important role, in term of the magnitude of the estimated coefficient, as it negatively and significantly impacts productivity. This is not surprising as the debate about productivity level seems to be very much demand related in that a decline in energy consumption by the business sector might be driving TFP. Closely allied to energy consumption is energy import which is measured as the fraction of imported energy in total energy consumption. We also find that energy import has a negative and statistically significant impact on productivity, though relatively smaller in term of magnitude when compared with the estimates of energy consumption. In most developed countries, especially Europe, national energy sector reform has been in favour of the energy transition where renewable generation displaces fossil fuel plants. Our findings confirm the effect of this pattern of energy transition on productivity as the estimated coefficient of renewable capacity is negative and statistically significant. The results suggest that an addition of renewable capacity accompanied by substantial increases in capital cost, in the face lower wholesale prices, might lead to lower revenue and an attendant decline in productivity. The results of the post financial crisis lend support to the claim in the literature that the structural break amplifies the decrease in productivity. This result also highlights the post-crisis productivity trend that continues to reinforce the apparent productivity puzzle.

Countries differ significantly in the way in which they regulate their energy market. We account for country heterogeneities on the assumption that energy market regulation will affect productivity given that the speed and extent of these regulatory intensity are different. To explore these variations, we follow the Duso et al. (2019) approach by splitting our sample into two subsamples i.e. high versus low regulation countries, at the median of the aggregate regulatory index for each sample country and year. This approach of using a sample division is straightforward and advantageous as it prevents the interaction of the regulatory indicators with arbitrarily selected macro variables that can influence TFP. Although, we use a dummy variable to capture the structural break associated with the global financial crisis on Table 8, we split our sample into two periods, before and after post financial crisis, to quantify the variation in the intensity of anticompetitive regulation influences on productivity over these periods, 1995-2007 and 2008-2017. The results for the country heterogeneities are reported in Table 9. The findings are generally consistent with the full sample analysis in Table 8, though some notable differences are observed.

For the regulatory intensity subsamples, the aggregate regulatory index is not significant in both high and low regulation samples. The results, however, show some immediate striking differences between the estimates of the coefficient on the entry barriers regulatory index. While the estimate of the coefficient on the entry barriers regulatory index is negative and has statistically significant influence on productivity for the high regulation countries, the estimate indicates no significant impact on productivity for countries with less anti-competitive regulation.

Table 9: The impact of regulation on total factor productivity level in the electricity and gas sector by subsamples

	lnTFP High Regulation		lnTFP Low Regulation		lnTFP Pre-Crisis		lnTFP Post-Crisis	
Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Aggregate index$_{t-1}$	0.0264		-0.00485		0.0304		-0.247***	
	(0.0248)		(0.0376)		(0.0278)		(0.0769)	
Entry barrier index$_{t-1}$		-0.0734***		0.00936		-0.0503***		-0.0818
		(0.0220)		(0.0219)		(0.0187)		(0.0562)
Public ownership index$_{t-1}$		0.0365		-0.0320		0.0751**		-0.142***
		(0.0292)		(0.0349)		(0.0304)		(0.0415)
Vertical integration index$_{t-1}$		0.0288		-0.0520		0.0509		-0.0126
		(0.0400)		(0.0493)		(0.0397)		(0.113)
Market structure index$_{t-1}$		0.121***		0.0143		0.104***		-0.0300
		(0.0336)		(0.0198)		(0.0272)		(0.0251)
GDP per capita$_{t-1}$	-1.735***	-1.556***	0.362	0.390	-0.745***	0.0251	-0.487	-0.401
	(0.331)	(0.555)	(0.247)	(0.260)	(0.267)	(0.381)	(0.383)	(0.410)
Energy consumption$_{t-1}$	0.323	0.646	-0.0522	-0.253	-0.649**	-0.371	0.631	0.361
	(0.306)	(0.537)	(0.355)	(0.404)	(0.258)	(0.431)	(0.454)	(0.507)
Energy imports $_{t-1}$	-0.00141***	0.00225*	0.00128	0.00108	-0.00194***	9.75e-05	-0.000983**	-0.00246
	(0.000328)	(0.00128)	(0.00188)	(0.00194)	(0.000580)	(0.00168)	(0.000409)	(0.00193)
Renewable capacity$_{t-1}$	-0.000513	0.00108	0.0228	0.0426	-0.113***	-0.176***	-0.133*	-0.134*
	(0.0397)	(0.0547)	(0.0493)	(0.0533)	(0.0369)	(0.0495)	(0.0681)	(0.0749)
Post financial crisis$_{t-1}$	-0.280**	-0.631***	-0.261*	-0.311**				
	(0.114)	(0.179)	(0.133)	(0.141)				
Constant	15.65***	11.89**	-4.936**	-4.387*	9.936***	0.718	3.487	3.647
	(2.675)	(4.842)	(2.242)	(2.387)	(2.274)	(3.513)	(3.321)	(3.531)
Observations	199	115	176	171	243	160	132	126
R-squared	0.606	0.738	0.557	0.556	0.276	0.409	0.444	0.489
Country FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES

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

Thus, this implies that firms operating under stricter regulation of entry in more anticompetitive countries have less incentive to make investments to increase productivity. Arguably, the results consistently point to entry barriers as the key constraint on productivity in the energy industries across the estimated models[27]. In contrast, we find increased market structure positively influencing productivity, which suggests that an increase in firm concentration in the market raises productivity. Results also suggest a fall in productivity for industrialized countries across the high regulation sample model, implying that regulation is actually stifling productivity in these economies as opposed to the low-regulation economies.

For the pre- and post- financial crisis periods, our findings show that the impact of regulation on productivity over these time periods is quantitively different. For the period 1995-2007, the coefficient estimate on the aggregate regulatory index is not statistically different from zero. However, the coefficient of entry barrier still has a negative and statistically significant effect on productivity while vertical integration and market structure coefficient estimates are positive and significant. For the period 2008-2013, the result clearly demonstrates a negative and highly statistical significant effect of aggregate regulation on productivity as opposed to the pre-crisis period. The finding suggests that despite the decrease in regulatory pressure over time in energy industries, as many countries are embarking on a path of deregulation, anticompetitive regulation remains a binding constraint to productivity. Interestingly, increased state control is found to exert an appreciable negative impact on productivity during this period. Comparatively, the evidence regarding the role played by public ownership appears to be inconclusive as positive influence is reported for the pre-crisis period but negative impact is recorded for the post-crisis period. The finding contradicts the widespread perception that often blames product market regulations for the poor performance of the majority of industrialized countries over the last few decades. This somewhat points to the productivity puzzle as argued by Card and Freeman (2002) that while the UK ranks highly in terms of pro-market reform measure, its productivity growth has not been remarkable.

[27]Alesina et al, (2005) also allude to entry liberalization as the most important component of regulatory reform on investment.

5.3. Productivity and climate policy

This section presents a first attempt at investigating the effect of climate policies on economy and energy sector productivity levels. We analyse separately the impact of two types of climate policies: carbon pricing mechanisms and feed-in-tariffs. As in section 5.2, the parameter estimates reported are from the estimation of a standard OLS (panel) model. The model includes both panel unit and time fixed effects, accounting for unobserved unit-specific/time-invariant and year-specific/unit-invariant effects, respectively. The number of observations available for each estimation is constrained by the observations available for the policy variables. The carbon pricing series are available through 2016 for all 22 panel countries while the Feed-in-Tariffs stringency variables are available through 2012 for 20 panel countries.[28] The panels are unbalanced.[29] The analysis is conducted at the level of the economy (Table 10) and the energy sector (Table 11).

Table 10 – Effect of climate policies on economy-wide productivity

	lnTFP (1)	lnTFP (2)	lnTFP (3)	lnTFP (4)	lnTFP (5)
ETS+Tax	-0.0029***				
	0.0006				
ETS price		0.0004			
		0.002			
Tax rate			-0.0031***		
			0.0007		
FiT wind				0.0034	
				0.0037	
FiT Solar					0.0018
					0.0036
GDP per capita	0.4277***	0.3568***	0.4153***	0.2088***	0.2336***
	0.0683	0.0693	0.0675	0.0974	0.0951
Energy consumption	-0.6871***	-0.5794***	-0.6896***	-0.5727***	-0.581***
	0.0885	0.0875	0.0881	0.1167	0.1164
Energy imports	-0.0004	-0.0003	-0.0004	-0.001	-0.0009
	0.0003	0.0003	0.0003	0.0004	0.0004
Renewable capacity	-0.0868***	-0.0815***	-0.0896***	-0.0845***	-0.0829***
	0.0098	0.01	0.0098	0.019	0.019
Post financial crisis	-0.2621***	-0.2769***	-0.2595***	-0.2063***	-0.217***
	0.0372	0.038	0.0371	0.0428	0.044
Constant	No	No	No	No	No

[28] Data for Estonia and Luxembourg are unavailable. Note that stringency variables are available through 2015 for some panel units.

[29] Some TFP observations are missing in some years of the sample for Estonia (1995-1999), Japan (2016).

Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations (N)	454	454	454	323	323
Adjusted R-squared	0.566	0.545	0.569	0.412	0.413

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

A few interesting observations emerge. First, economy level column 1 suggests that carbon pricing mechanisms as a whole (tax and ETS together) had a substantial negative impact on an economy's aggregate TFP. For every $1 increase in the average, economy-wide, price of carbon, the TFP decreases by 0.3%. However, interestingly, subsequent estimations at the economy level (columns 2 and 3) analysing the separate effects of carbon taxes and ETS suggest that this effect is mostly driven by the countries that introduced carbon taxes. These estimations show that the latter exhibits almost no effect on TFP while the effect of the former is statistically different from 0 and of a magnitude close to that estimated in column 1. In our sample, Finland, Norway, Sweden, Denmark, Slovenia, Estonia, Japan, France introduced and maintained a carbon tax scheme in place throughout all years in the sample.

The stringency of wind and solar FiT schemes only exhibits a weak correlation with the total factor productivity of the economy. However, the level of installed renewable capacity, which was in many countries at least in part supported by these schemes, shows a strong negative relationship with the economy's total factor productivity. This effect is quantitatively similar to that identified in section 5.2, i.e. any 1% increase in renewable installed capacity was associated with 0.01% decrease in TFP.

There is less evidence, however, that climate policies captured by the variables used in this analysis had any strong impact on the TFP of the energy sector. Pricing policies seem to have had only a very small negative effect on the TFP of the energy sector. For every $1 increase in the price of CO_2 emissions, the average decrease in TFP is 0.02%. The magnitude of this effect is, as noted at the economy level, slightly stronger for carbon taxes than emissions trading systems. The distribution of these estimates is such, however, that they cannot be confidently identified as different from 0. A similar pattern emerges for the effect of FiTs (wind and solar separately) on the energy sector's TFP. Coefficient estimates for both variables are positive but there is little to no support that these are statistically different from 0.

Overall, these results do not support the hypothesis that climate policies have had a substantial *direct* impact on the productivity of the energy sector, either positive or negative. However, we note that an intended effect of these policies was to induce the deployment (and economic dispatch) of renewable energy generation capacity and that, across all estimated models, there is strong evidence that this deployment had a negative impact on both the economy's and the energy sector's TFP.

Table 11 – Effect of climate policies on energy sector productivity

	lnTFP (6)	lnTFP (7)	lnTFP (8)	lnTFP (9)	lnTFP (10)
ETS+Tax	-0.0015				
	0.0007				
ETS price		-0.0011			
		0.001			
Tax rate			-0.0016		
			0.0009		
FiT wind				0.0023	
				0.0032	
FiT Solar					0.0005
					0.0031
GDP per capita	-0.0346	-0.0387	-0.0399	-0.2126*	-0.197*
	0.0585	0.0587	0.0585	0.0839	0.0819
Energy consumption	-0.4296	-0.4296***	-0.4391***	-0.1623	-0.1685
	0.0737	0.0742	0.0738	0.1005	0.1002
Energy imports	-0.0009***	-0.001***	-0.0009**	-0.0009*	-0.0008*
	0.0003	0.0003	0.0003	0.0004	0.0004
Renewable capacity	-0.0211*	-0.023**	-0.0222**	-0.0728***	-0.0718***
	0.0085	0.0085	0.0085	0.0164	0.0164
Post financial crisis	-0.1412***	-0.1365***	-0.1476***	-0.0155	-0.0207
	0.0323	0.0327	0.0326	0.0369	0.0379
Constant	No	No	No	No	No
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations (N)	448	448	448	323	323
Adjusted R-squared	0.462	0.458	0.46	0.249	0.248

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

The results presented above highlight differences in the implications of climate policies at the economy and energy sector level. While columns 6 to 10 provide no robust evidence of a *direct* impact of climate policies on energy sector productivity, economy-level models (1 to 5) suggest a negative average impact of carbon taxes on the economy's TFP. Taken together, these two observations point to the possibility that the negative impact of carbon taxes on the economy's productivity originated in other sectors than the energy sector. In particular, it might have originated in manufacturing sectors covered by carbon taxes. However, to date, virtually all studies have investigated the impact of the EU ETS and the few studies that have analysed the implications of carbon taxes for productivity. Commins et al. (2011) and Martin et al. (2014), focused on manufacturing sectors and came to different conclusions. This calls for further investigation of the role played by carbon taxes in determining manufacturing sectors' productivity.

The analysis highlights another important point: that climate policies can affect [firm, sector, economy] productivity through several channels. First, it can induce change in real capital and/or labour expenditures. As mentioned before, both carbon pricing and feed-in-tariffs have induced power generation utilities to invest in new renewable generation capacity.[30] However, given the intermittent nature of power produced by these generation technologies, their deployment has led to little retirement of older capital stock. A larger capital stock and relatively stable output in the energy sector might therefore explain part of the productivity slow down. The negative relationship between installed renewable capacity and productivity identified across all models estimated lends support to this explanation and points to an indirect link between support for renewable generation capacity deployment and TFP, i.e. one that is mediated through the actual deployment of such capacity.

Second, climate policies could induce technological improvement leading to, for example, enhanced operational efficiency of existing or new plants. The strong version of the Porter Hypothesis posits that this would eventually lead to productivity improvements. However, results for the energy sector provide little support for this hypothesis in our context and results for economy-level models point to a negative effect of carbon taxes on productivity. Indeed, this seems unlikely in that higher renewables reduce utilisation of existing fossil-fuel plants, reducing their productivity.

Third, we note that the productivity measure used in this study is based on value added, which is sensitive to variations in output prices. Since, carbon pricing policies aim at raising the cost

[30] Alongside these two policies, Renewable Energy targets forced utilities to invest heavily in the deployment of renewable electricity generation capacity.

of polluting inputs to (or polluting by-products of) the production process, there is at least the theoretical possibility that some of the variation in output price resulting from such policies will be accounted for as a change in productivity (Lutz, 2016). The extent of this effect at the firm or industry level depends on the pass-through rate and pollution intensity. In the energy sector, there is some evidence that emissions costs are passed through to electricity prices by utilities (e.g. Fabra & Reguant, 2014), which would imply that some of the energy sector value added was not lost.[31] The question remains as to whether higher RES by depressing gas and electricity prices contributed to lower measured value added and hence productivity growth.

Finally, we emphasise that these results are obtained at the sectoral and economy level and that that the dynamics uncovered at the industry-level may be affected by resource reallocation among firms (Albrizio et al., 2017). Therefore, investigating the relationship between climate policies and productivity at the firm level should provide additional insights.

6. Conclusion

We have undertaken three sets of analysis in this paper examining TFP in a sample of OECD countries over the period 1995-2016.

The first looked at TFP growth in the whole economy and in the electricity and gas sectors. We investigated the correlations between the various productivity measures and their components over time. The second focused on explaining the level of TFP in the electricity and gas sector with respect to energy market reform and competition. The third focused on relating the level of TFP in both the whole economy and the electricity and gas sector to climate and energy policy, as measured by carbon pricing and renewables policies (i.e. Feed-in Tariffs).

We find that there is a substantial productivity puzzle for the electricity and gas sectors specifically. TFP growth is lower in electricity and gas than in the economy as a whole and falls post-financial crisis. TFP levels can only be weakly explained by changes to the competitive environment of the energy sector. However, more importantly we find evidence that energy and climate policy has negatively and significantly reduced energy sector productivity, at the same time as increasing capital input to the sector. Further, we find that the

[31] A more recent development with the potential to raise marginal cost is the increasing scarcity of suitable sites for utility-scale renewable power generation installation (Lancker and Quaas, 2019).

strength of energy and climate policy is positively correlated with slower overall TFP.

The results of our analysis have important policy implications.

First, the productivity puzzle does exist in the energy network sectors, particularly in electricity and gas. If anything there is more of a productivity puzzle in the electricity and gas sectors than in the whole economy. We clearly show that in spite of large amounts of capital being put into these sectors, TFP has fallen. This is worthy of further study.

Second, the productivity puzzle at the whole economy level in OECD countries would seem to at least be partly due to more ambitious environmental policy. Hence environmental policies need to pay more attention to their impact on productivity both within the electricity and gas sectors but also across the whole economy.

Third, we do not find evidence for 'green growth' arising from more stringent and more input intensive environmental and renewables policies. Such policies bring welfare benefits in terms of a cleaner environment but they do not show up in current measures of TFP. Advocates for 'green growth' strategies need to better measure and articulate the welfare benefits of such strategies.

References

Abramovich, M. (1956), 'Resource and output trends in the USA since 1870', *American Economic Review*, 46:5-23.

Adarov, A. and Stehrer, R., 2019. *Tangible and Intangible Assets in the Growth Performance of the EU, Japan and the US*. Vienna Institute for International Economic Studies.

Ajayi, V., Weyman-Jones, T. and Glass, A., 2017. Cost efficiency and electricity market structure: a case study of OECD countries. *Energy Economics*, *65*: 283-291.

Ajayi, V., Anaya, K. and Pollitt, M., 2018. Productivity growth in electricity and gas networks since 1990: Report prepared for the Office of Gas and Electricity Markets (OFGEM).

Albers, R. and Vijselaar, F., 2002. *New technologies and productivity growth in the euro area* (No. 122). ECB Working Paper.

Albrizio, S., Kozluk, T. and Zipperer, V., 2017. Environmental policies and productivity growth: Evidence across industries and firms. *Journal of Environmental Economics and Management*, *81*: 209-226.

Alesina, A., Ardagna, S., Nicoletti, G. and Schiantarelli, F., 2005. Regulation and investment. *Journal of the European Economic Association*, *3*(4): 791-825.

Ambec, S., Cohen, M.A., Elgie, S. and P. Lanoie (2013). The Porter Hypothesis at 20: can environmental regulation enhance innovation and competitiveness? Rev. Environ. Econ. Policy 7 (1): 2–22.

Barone, G. and Cingano, F., 2011. Service regulation and growth: evidence from OECD countries. *The Economic Journal*, *121*(555): 931-957.

Botta, E. and T. Kozluk (2014), "Measuring Environmental Policy Stringency in OECD Countries: A Composite Index Approach", *OECD Economics Department Working Papers*, No. 1177, OECD Publishing, Paris. http://dx.doi.org/10.1787/5jxrjnc45gvg-en

Buccirossi, P., Ciari, L., Duso, T., Spagnolo, G. and Vitale, C., 2013. Competition policy and productivity growth: An empirical assessment. *Review of Economics and Statistics*, *95*(4): 1324-1336.

Bourlès, R., Cette, G., Lopez, J., Mairesse, J. and Nicoletti, G., 2013. Do product market regulations in upstream sectors curb productivity growth? Panel data evidence for OECD countries. *Review of Economics and Statistics*, *95*(5): 1750-1768.

Brau, R., Doronzo, R., Fiorio, C.V. and Florio, M., 2010. EU gas industry reforms and consumers' prices. *The Energy Journal*, *31*(4): 167-182.

Card, D. and Freeman, R.B., 2002. What Have Two Decades of British Economic Reform Delivered in Terms of Productivity Growth?. *International Productivity Monitor*, *5*: 41-52.

Calligaris, S., F. Arcangelo and G. Pavan (2018), “The Impact of European Carbon Market on Firm Productivity: Evidences from Italian Manufacturing Firms”, *Working paper*.

Cobbold, T. (2003), *A Comparison of Gross Output and Value-Added Methods of Productivity Estimation.* Productivity Commission Research Memorandum, Canberra.

Cohen, M. and A. Tubb (2018), “The Impact of Environmental Regulation on Firm and Country Competitiveness: A Meta-Analysis of the Porter Hypothesis”, *Journal of the Association of Environmental and Resource Economists*, Vol. 5/2: 371-399, http://dx.doi.org/10.2139/ssrn.2692919.

Commins, N. et al. (2011), “Climate Policy & Corporate Behavior”, *The Energy Journal*, Vol. 32/4: 51-68, http://dx.doi.org/10.5547/ISSN0195-6574-EJ-Vol32-No4-3.

Conway, P. and Nicoletti, G., 2006. Product market regulation in the non-manufacturing sectors of OECD countries: measurement and highlights. OECD Economics Department Working Papers, No. 530, OECD Publishing, Paris.

Corrado, C., Lengermann, P., Bartelsman, E.J. and Beaulieu, J.J., 2007. Sectoral productivity in the United States: Recent developments and the role of IT. *German Economic Review*, *8*(2): 188-210.

Crafts, N., 2006. Regulation and productivity performance. *Oxford Review of Economic Policy*, *22*(2): 186-202.

Crafts, N. and Mills, T.C., 2020. Is the UK productivity slowdown unprecedented?. *National Institute Economic Review*, *251*: R47-R53.

Daveri, F., 2002. The new economy in Europe, 1992–2001. *Oxford Review of Economic Policy*, *18*(3): 345-362.

Duso, T. and Seldeslachts, J., 2010. The political economy of mobile telecommunications liberalization: Evidence from the OECD countries. *Journal of Comparative Economics*, *38*(2): 199-216.

Duso, T., Seldeslachts, J. and Szucs, F., 2019. The impact of competition policy enforcement on the functioning of EU energy markets. *The Energy Journal*, *40*(5): 97-120.

EC, 2012. Analysis of options beyond 20% GHG emission reductions: Member State results. European Commission Staff Working Paper. Available online :
https://ec.europa.eu/clima/sites/clima/files/strategies/2020/docs/swd_2012_5_en.pdf (assessed on 22 June, 2020)

Fabra, Natalia, and Mar Reguant. 2014. "Pass-Through of Emissions Costs in Electricity Markets." American Economic Review, 104 (9): 2872-99.

Ferguson, R.W. and Wascher, W.L., 2004. Distinguished lecture on economics in Government: lessons from past productivity booms. *Journal of Economic Perspectives*, *18*(2): 3-28.

Grajek, M. and Röller, L.H., 2012. Regulation and investment in network industries: Evidence from European telecoms. *The Journal of Law and Economics*, *55*(1): 189-216.

Griffith, R., Redding, S. and Reenen, J.V., 2004. Mapping the two faces of R&D: Productivity growth in a panel of OECD industries. *Review of economics and statistics*, *86*(4): 883-895.

Gust, C. and Marquez, J., 2004. International comparisons of productivity growth: the role of information technology and regulatory practices. *Labour economics*, *11*(1): 33-58.

Hassan, F. and Ottaviano, G., 2013. Productivity in Italy: The great unlearning. *VoxEU. org*, *30*.

Hausman, W.J. and Neufeld, J.L., 2011. How politics, economics, and institutions shaped electric utility regulation in the United States: 1879–2009. *Business History*, *53*(5): 723-746.

International Energy Agency: Electricity Information (2019 Edition). UK Data Service. https://doi.org/10.5257/iea/elec/2019

International Energy Agency: Renewables Information (2019 Edition). UK Data Service. DOI: https://doi.org/10.5257/iea/ri/2019

International Energy Agency: World Energy Balances (2019 Edition). UK Data Service. https://doi.org/10.5257/iea/web/2019

Inklaar, R., Timmer, M.P. and Van Ark, B., 2008. Market services productivity across Europe and the US. *Economic Policy*, *23*(53): 140-194.

Jaffe, A. B. and K. Palmer (1997), Environmental Regulation and Innovation: A Panel Data Study, *The Review of Economics and Statistics*, 79(4): 610-61

Jorgenson, D.W., 2001. Information technology and the US economy. *American Economic Review*, *91*(1): 1-32.

Jorgenson, D.W., Ho, M.S. and Stiroh, K.J., 2006. Potential growth of the US economy: will the productivity resurgence continue?. *Business Economics*, *41*(1): 7-16.

Jorgenson, D. W., Griliches, Z. (1967), 'The explanation of productivity change', *Review of Economic Studies*, 34: 349-383.

Jorgenson, D.W., Gollop, F., Fraumeni, B. (1987), *Productivity and the U.S. Economic Growth*, Amsterdam.

Kendrick, J.W. (1961), *Productivity Trends in the United States.* Princeton University Press, Princeton.

Kozluk, T., Zipperer, V. (2014). Environmental policies and productivity growth: a critical review of empirical findings. OECD J.: Econ. Stud. 2014 (1), 155–185.

Levinsohn, J. and Petrin, A., 2003. Estimating production functions using inputs to control for unobservables. *The Review of Economic Studies*, *70*(2): 317-341.

Lundgren, T., P. Marklund, Samakovlis, E. and W. Wenchao (2015), "Carbon prices and incentives for technological development", *Journal of Environmental Management*, Vol. 150, https://www.sciencedirect.com/science/article/pii/S0301479714005921: 393-403.

Lutz, B. (2016), "Emissions trading and productivity: Firm-level evidence from German manufacturing", *Discussion Paper 16-067, Centre for European Economic Research*, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2850541.

Martin, R., M. Muûls and U. Wagner (2016), "The Impact of the EU ETS on Regulated Firms : What is the Evidence After Ten Years ?", *Review of Environmental Economics and Policy*, Vol. 10/1: 129-148.

Miller, B. and Atkinson, R.D., 2014. Raising European productivity growth through ICT. *ITIF, June*.

Nicoletti, G. and Scarpetta, S., 2003. Regulation, productivity and growth: OECD evidence. *Economic policy*, *18*(36): 9-72.

OECD (2001), *Productivity Manual: A guide to the Measurement of Industry-level and Aggregated Productivity Growth*, OECD, Paris.

Oliner, S.D. and Sichel, D.E., 2000. The resurgence of growth in the late 1990s: is information technology the story?. *Journal of economic perspectives*, *14*(4): 3-22.

Oulton, N. (2000), *Must Growth Rates Decline? Baumol's Unbalanced Growth Revisited.* Bank of England Working Paper No. 107, Jan. 2000.

Palmer, K., W. E. Oates, and P. R. Portney (1995), "Tightening Environmental Standards: The Benefit-Cost or No-Cost Paradigm?" *Journal of Economic Perspectives*, 9(4): 119-132.

Pollitt, M.G., 2012. Lessons from the history of independent system operators in the energy sector. *Energy Policy*, *47*: 32-48.

Porter, M.E. (1991), "America's green strategy", *Scientific American*, 264 (4): 96.

Schreyer, P. (2000), *The contribution of information and communication technology to output growth: a study of the G7 countries* (No. 2000/2). OECD Publishing.

Solow, R.M. (1957), 'Technical change and the aggregate production function', *Review of Economics and Statistics* 39: 312-320.

Stehrer, R., A. Bykova, K. Jäger, O. Reiter, and M. Schwarzhappel (2019), Industry level growth and productivity data with special focus on intangible assets, Deliverable 3 for DG ECFIN project Contract No. 2018 ECFIN-116/SI2.784491; wiiw Statistical Report 8, The Vienna Institute for International Economic Studies.

Timmer, M., van Moergasterl, T., Stuivenwold, E., Ypma, G., O'Mahony M., Kangasniemi, M. (2007), *EU KLEMS Growth and Productivity Accounts. Version 1.0. Part 1 Methodology*, EUKLEMS, Mar. 2007.

Van Ark, B., Melka, J., Mulder, N., Timmer, M. and Ypma, G., 2002. ICT investment and growth accounts for the European Union, 1980-2000. *Brussels, European Commission, June*.

Van Ark, B. and Jäger, K., 2017. Recent Trends in Europe's Output and Productivity Growth Performance at the Sector Level, 2002-2015. *International Productivity Monitor*, (33): 8-23.

Van Ark, Bart, Mary O'Mahoney, and Marcel P. Timmer. "The productivity gap between Europe and the United States: Trends and causes." *Journal of economic perspectives* 22(1): 25-44.

Van der Wiel, H.P. (1999), *Sectoral Labour Productivity Growth.* Research Memorandum N. 158, CPB Netherlands Bureau for Economic Policy Analysis, The Hague.

Appendix

Figure A1: Trends of Total Factor Productivity growth by Country

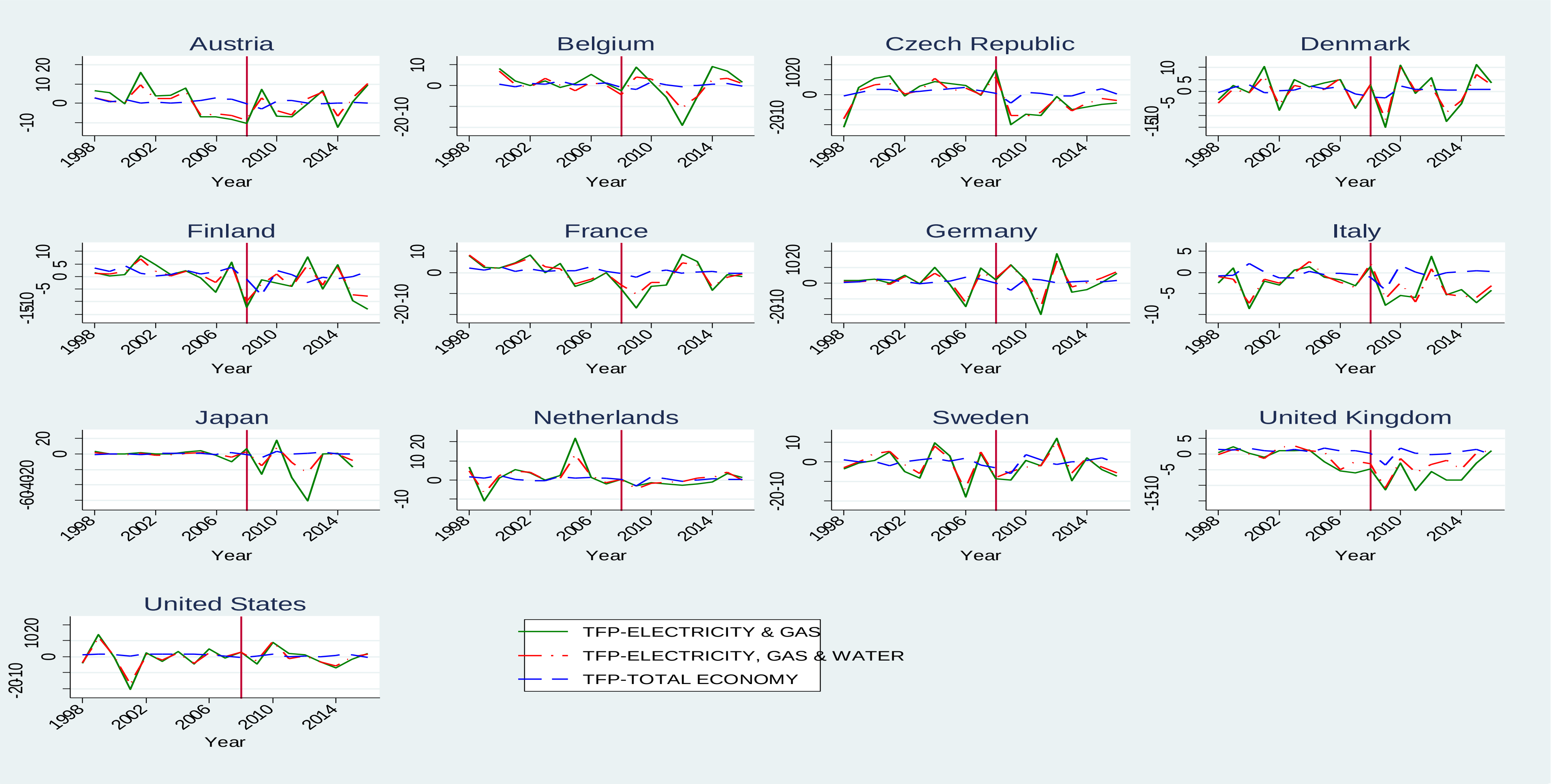


Table A1: Electricity & Gas, and Total Economy TFP growth correlation, 1998-2007

	E&G	*Total economy*
E&G	1	
Total economy	0.1172	1

Table A2: Electricity & Gas, and Total Economy TFP growth correlation, 2008-2016

	E&G	*Total economy*
E&G	1	
Total economy	0.1073	1

Table A3: Capital Input Growth Correlation-Total Economy

	IntangOIPP	*IntangRD*	*IntangSoftDB*	*TangICT*	*TangNICT*	*Capital input growth*
IntangOIPP	1					
IntangRD	0.1271**	1				
IntangSoftDB	0.0127	-0.2971***	1			
TangICT	0.1288**	0.1480**	0.1809***	1		
TangNICT	0.0247	0.0764	0.1049	0.2821***	1	
Capital input growth	0.1111*	0.2308***	0.2793***	0.5293***	0.9322***	1

Table A4: Capital Input Growth Correlation- Electricity and Gas Sectors

	IntangOIPP	*IntangRD*	*IntangSoftDB*	*TangICT*	*TangNICT*	*Capital input growth*
IntangOIPP	1					
IntangRD	-	1				
IntangSoftDB	-	-0.1023	1			
TangICT	-	0.0441	-0.0748	1		
TangNICT	-	-0.1009	-0.0044	0.1528**	1	
Capital input growth	-	0.0619	0.0240	0.3426***	0.9673***	1

Table A5: Product market regulation indices correlation

	Aggregate	Entry barrier	Public ownership	Vertical integration	Market Structure
Aggregate	1				
Entry barrier	0.8565***	1			
Public ownership	0.7411***	0.3827***	1		
Vertical integration	0.7522***	0.7345***	0.3663***	1	
Market Structure	0.8628***	0.5892***	0.5254***	0.4404***	1

Table A6: The impact of regulation on total factor productivity level for the electricity and gas sector, 1995-2016

	Full Sample	High regulation	Low regulation	Pre-Crisis	Post-Crisis
	(1)	(2)	(3)	(4)	(5)
Variables	lnTFP	lnTFP	lnTFP	lnTFP	lnTFP
Aggregate index	-0.0361*	0.0312	-0.0492	-0.00304	-0.0594
	(0.0214)	(0.0291)	(0.0349)	(0.0286)	(0.0546)
GDP per capita$_{t-1}$	0.378***	-1.246***	0.00613	-0.213	0.0956
	(0.140)	(0.355)	(0.180)	(0.280)	(0.228)
Energy consumption$_{t-1}$	-0.672***	0.229	0.203	-0.595**	0.0896
	(0.176)	(0.303)	(0.242)	(0.251)	(0.296)
Energy imports$_{t-1}$	-0.00212***	-0.00115	0.00211**	-0.000834	-0.000319
	(0.000675)	(0.00100)	(0.000845)	(0.000942)	(0.00111)
Renewable capacity$_{t-1}$	-0.100***	-0.0392	-0.0139	-0.126***	-0.107**
	(0.0202)	(0.0473)	(0.0353)	(0.0380)	(0.0423)
Post financial crisis$_{t-1}$	-0.619***	-0.480**	-0.179		
	(0.0990)	(0.214)	(0.114)		
Constant	-0.502	12.21***	-0.979	5.215**	-0.512
	(1.234)	(2.899)	(1.535)	(2.370)	(1.870)
Observations	400	197	203	220	180
R-squared	0.520	0.564	0.639	0.226	0.518
Country FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES

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