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Trade-Facilitated Technology Spillovers in Energy Productivity Convergence Processes across EU Countries

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ABSTRACT

This empirical paper tests for trade-facilitated spillovers in the convergence of energy productivity across 16 European Union (EU) countries from 1995 to 2005. One might anticipate that by inducing specialization, trade limits the potential for convergence in energy productivity. Conversely, by inducing competition and knowledge diffusion, trade may spur sectors to greater energy productivity. Unlike most previous work on convergence, we explain productivity dynamics from cross-country interactions at a detailed sector level and apply a spatial panel data approach to explicitly account for trade-flow related spatial effects in the convergence analysis. Our study confirms the existence of convergence in manufacturing energy productivity, caused by efficiency improvements in lagging countries, while undermined by increasing international differences in sector structure. Further, we find that trade flows explain 30 to 40 percent of the unobserved variation in energy productivity. Trade continues to explain the unobserved variation in energy productivity even after accounting for geographic proximity. Last, we find that those countries and sectors with higher dependence on trade both have higher energy productivity growth and a higher rate of convergence, further implying that trade can enhance energy productivity. Thus, unlike concerns that trade may spur a 'race to the bottom', we find that promoting trade may help stimulate energy efficiency improvements across countries.

KEY WORDS: Energy Productivity, Convergence, Spillovers, Technology Transfer, Sector Analysis, Spatial Panel

1. INTRODUCTION

High energy prices, domestic energy security and disruptive global warming are making energy efficiency a priority for many governments (IEA 2012, GEA 2012). Despite this common goal, energy use varies widely across countries, with Finland having a per capita energy use more than one quarter higher than that of Sweden, more than twice that of the UK and three times higher than Portugal (World Bank 2014). Cross-country differences in energy efficiency or energy productivity, defined as the ratio of economic output to energy input, are largely determined by differences in relative factor prices, patterns of specialization, and the level and direction of technological development (e.g. Berndt and Wood 1975, Jorgenson 1984, Popp et al. 2010, Fisher-Vanden et al. 2004, Mulder 2005, Smulders and De Nooij 2003, Sue Wing 2008). Energy-saving technological change results not only from domestic innovation but also from foreign technology diffusion (Bosetti et al. 2008, Hall and Helmers 2013, Popp 2006; 2011, Verdolini and Galeotti 2011). In this paper we study what factors contribute to improvements in industrial energy productivity and in particular, we ask whether growth in energy productivity is affected by trade.

Trade can influence the use of energy in production through various channels. Depending on which mechanism prevails, trade may contribute to either increasing or decreasing variation in energy productivity levels across countries. On the one hand, trade linkages may help reduce productivity gaps among countries by accelerating knowledge diffusion, equalizing factor prices and encouraging adoption of common environmental regulation (e.g. Alcalá and Ciccone 2004, Coe et al. 1997, Coe and Helpman 1995, Comin and Hobijn 2004, Hayami and Ruttan 1985, Holmes and Schmitz 2001, Leimbach and Baumstark 2010, Lovely and Popp 2011, Parrado and De Cian 2014, Waugh 2010). On the other hand, trade may stimulate international specialization and spatial separation, which could lead to the divergence of factor productivity (Copeland and Taylor 1999, Grossman and Helpman 1991, Young 1991).

The extent to which these mechanisms facilitate or hinder less productive countries from catching up with more advanced economies depends on a variety of local characteristics, including sector composition, human capital and energy resource endowments, environmental stringency and distance to the trading partner. From a micro-perspective, to maintain a competitive advantage in the face of trade, firms have strong incentives to develop and commercialize new energy technologies. From a macro-perspective, firms that trade tend to be more productive than their domestic peers (Melitz 2003) and one dimension of productivity is energy use. By increasing the reach of these high productivity firms, domestic firms will arguably also have to increase their energy productivity to remain competitive.

Conversely, in the case of a highly regulated input like energy, trade might also induce countries to 'race to the bottom', where a country weakens regulations and/or decreases energy prices to exploit its comparative advantage (Levinson 2003, Copeland and Taylor, 2004). Cheap energy reduces the domestic demand for energy efficiency, and so the home market will not serve as a springboard for the international commercialization of energy-saving technology (Urpelainen, 2011). Further, local abundance of energy resource endowments may facilitate specialization in energy-intensive industries by suppressing domestic energy prices, thus contributing to structural divergence of production structures across countries (Gerlagh and Mathys 2011, Mulder and De Groot 2012). Trade-induced international knowledge spillovers may benefit different sectors in different ways (Giannetti 2002), decline with geographical or cultural distance (Keller 2002, Lankhuizen et al. 2011, Verdolini and Galeotti 2011) and require certain 'social capabilities' to successfully turn them into productivity gains (e.g. Abramovitz 1986, Cohen and Levinthal 1990). Thus, it is not clear whether trade flows or other spillover mechanisms will induce convergence or divergence in country energy productivity.

We focus our analysis on the use of energy in the manufacturing sector across a sample of 16 European countries from 1995-2005. Apart from data availability (see below) this choice is motivated by the fact that the European Union (EU) is one of the regions in the world where the increase in bilateral trade has been especially strong due to its unique process of market integration. The value of internal trade among the EU-25 member states has approximately doubled in the period 1995-2005.[1] In addition, manufacturing goods comprise the vast majority of trade volume, while the manufacturing sector is still responsible for about one-third of total energy consumption in the EU. Specifically, we test to what extent trade has contributed to either convergence or divergence of energy productivity levels across countries.

Cross-country differences in aggregate energy productivity result from differences in energy technology at the sector and firm level, as well as from differences in the structure of the countries' economies. This structural effect is caused by the fact that some production processes inherently require more energy inputs than others, relative to capital and labor inputs. In the field of energy studies, a popular line of research has been to separate the efficiency effect from the structural effect on energy productivity by means of index number decomposition analysis (for surveys see Ang and Zhang 2000 and Liu and Ang 2007). Recent evidence from this literature shows that the role of the structure effect in explaining aggregate energy productivity patterns is not only sizeable but also increasing in importance over time (e.g. Fisher-Vanden et al. 2004, IEA 2004, Huntington 2010, Ma and Stern 2008, Mulder and De Groot 2012, Unander 2007, Weber 2009). Moreover, cross-country differences in energy

[1] Source: Eurostat Statistical Yearbook.

productivity levels appear to be mainly driven by differences in the structure of economies. For example, Taylor et al. (2010) find that in 2005 structural effects are responsible for almost half of the variation in manufacturing energy intensities across developed countries. Duro et al. (2010) and Mulder and De Groot (2012) find that aggregate convergence patterns are predominantly caused by trends in energy efficiency, while structural changes tend to attenuate cross-country energy convergence. Mulder (2105) finds that increasing international differences in sector structure undermine convergence of manufacturing energy intensity levels.

Clearly, the increasing role of economic structure in aggregate energy productivity dynamics is related to the increase in international trade, given the fact that trade flows influence the structure of economies through its impact on (changing) production patterns. Existing literature does not yet provide us with a clear understanding of the role of trade as determinant of cross-country variation in energy productivity over time. Mulder (2015) finds a striking similarity in the timing of a trend-break towards increasing cross-country variation of specialization patterns and the trend-break towards decreasing cross-country variation of manufacturing energy intensity levels after 1995. Hence, his work indicates that since the second half of the 1990s, increasing trade and market integration appear to have helped reducing energy productivity gaps across countries but that this relation deserves to be carefully tested for in future work. This paper aims to empirically test for trade-facilitated spillovers in manufacturing energy productivity convergence. In doing so, we address two shortcomings in the literature to date. First, in our estimates of convergence, we explicitly control for spatial dependence, using spatial econometric tools to account for trade-flow related spatial effects in the convergence analysis. Second, we exploit a relatively high level of sector detail, allowing for the identification of productivity patterns across a range of manufacturing subsectors, including both energy-intensive and energy-extensive industries.[2]

Following the seminal work by Baumol (1986), Abramovitz (1986), Barro and Sala-i-Martin (1992), numerous empirical convergence studies have been published in the macroeconomic literature, typically presenting evidence of convergence of per capita income, labor productivity or total factor productivity (for good surveys see Abreu et al. 2005, a special issue of the Economic Journal 1996 and Islam 2003). Various authors have presented evidence of misspecification in convergence estimations due to unaccounted for spatial dependence (Rey and Montouri, 1999; Rey and Janikas, 2005; Florax and Nijkamp, 2005). This concern has been addressed in recent studies that use spatial econometric techniques to address the role of 'spatial phenomena' like technology diffusion, trade and factor mobility in driving convergence patterns. (e.g. Amstrong 1995; Rey and Montouri 1999; Fingleton and McCombie 1998, Fingleton 1999, Lopez-Bazo et al. 1999).

Convergence analyses emerged more recently in the field of energy and environmental economics, (see, for example, Aldy 2006, Duro et al. 2010, Duro and Padilla 2011, Jakob et al, 2012, Liddle 2009, 2010, Markandya et al. 2006, Miketa and Mulder 2005, Mulder and De Groot 2007, 2012, Mulder et al. 2011, Romero-Avila 2008, Sun 2002). However, these convergence studies do not explicitly control for spatial dependence in their search for factors that may explain the evolution of cross-country differences in energy productivity. A notable exception is Mulder et al. (2011) who find that a country's energy productivity development is influenced by the spatially weighted average of the energy productivity growth rates of its

[2] One shortcoming of our approach is that we do not observe the potential increased transportation energy use driven by trade. In as much as trade induces a greater flow of goods and thus an increase in transportation, our analysis will miss this potentially large increase in energy demand (Hummels 2007, 2008; Gabel and Roller, 1992 and Hecht 1997).

neighboring countries. Moreover, they show that in terms of energy productivity performance, Western European countries over time have become more homogenous while various Eastern European countries have been able to catch up to this group. Their analysis, however, contains insufficient sector detail and explanatory variables to explain these cross-country spatial interactions.

To the best of our knowledge this paper is the first to explain energy productivity dynamics from specified cross-country spatial interactions at a detailed sector level. Second, we make use of a recently developed dataset that uses a common framework to derive cross-country data series for energy consumption and value added at the sectoral level. As a result, unlike many previous studies in this field that use different data sources, we (largely) avoid problems in defining sectors consistently across energy and economic variables. Also, these data allow us to exploit a relatively high level of sector detail, as noted before. In addition, we use sector-level trade transaction data to proxy for the intensity of technology spillovers, as opposed to the country-level trade transaction data. Taking into account sectoral heterogeneity is important because aggregate productivity analyses may lead us to overlook structural changes within the manufacturing sector, which in turn masks substantial sub-sectoral differences in energy productivity convergence dynamics. This level of detail is especially important given our focus on the role of trade as a potentially important source of knowledge spillovers, because technologies are likely to be more transferrable within a sector than across sectors.

Third, to our knowledge, our paper is one of the first to use country by sector trade flows as a measure of 'proximity' in place of standard geographic weights. We then use spatial econometric techniques to test for the hypothesis that increasing trade facilitates cross-country convergence of energy productivity performance. The underlying idea is that trade rather than geographical proximity per se stimulates energy productivity growth in relatively backward countries, amongst others, because it facilitates diffusion of knowledge about state-of-the-art energy efficient technologies and contributes to factor price equalization and the need to maintain a competitive advantage by increasing efficiency.

The structure of the paper is organized as follows. Section 2 presents the methodology and theoretical background of our analysis. In section 3 we describe the data and the empirical approach used in our analysis. In section 4 we provide a descriptive analysis of trends in energy efficiency, trade flows and production patterns within Europe. These stylized facts help to further motivate our research question and to guide the analysis. Section 5 reports and interprets the empirical analytical results of the spatial panel energy productivity convergence models. Section 6 concludes.

2. Methodology

We first define a production function that takes factor inputs capital (K), labor (L) and energy (E), and converts them into marketable output (Y). Following the popular fashion of Charles Cobb and Paul Douglas (1928) on defining a production function that allows inputs (K and L) to change in magnitude in response to changes in factor prices, many energy economics researchers (e.g. Saunders, 2008) incorporate energy (E) as an additional input to allow constant elasticity of substitution among factors. Therefore, in this paper we assume a standard neoclassical Cobb-Douglas production function, such that output in country *i* in time *t* (Y_{it}), is produced using labor (L_{it}), capital (K_{it}), and energy (E_{it}):

$$Y_{it} = A_{it} K_{it}^{\alpha} L_{it}^{\beta} E_{it}^{\gamma} \ , \tag{1}$$

where A_{it} is a country-specific input-augmentation coefficient, measuring technological progress. Assuming that each input is paid according to its marginal product, equation (1) can be rewritten in terms of average energy productivity EP_{it} (defined as Y_{it} / E_{it}) as follows:

$$EP_{it} = A_{it} \left[\frac{K_{it}}{E_{it}}\right]^{\alpha} \left[\frac{L_{it}}{E_{it}}\right]^{\beta} = A_{it} \left[\frac{\alpha p_e}{(1-\alpha-\beta)r}\right]^{\alpha} \left[\frac{\beta p_e}{(1-\alpha-\beta)w}\right]^{\beta} \quad (2)$$

with r, w and p_e indicating, respectively, the rental price of capital, the wage rate and the energy price. Equation (2) shows that cross-country differences in energy productivity may rise from differences in factor input ratios, (relative) factor prices and the degree of technological advancement. Accordingly, transitional dynamics is driven by factor accumulation, factor price changes and technological change, under the influence of processes like trade, foreign direct investment (FDI), learning and market conditions (Lucas 1988, Romer 1990, Solow 1956).

Within this framework, countries may converge to a global or a local steady state, depending on the extent to which convergence processes are conditional on country-specific factors (Barro and Sala-i-Martin 1992, Economic Journal 1996). As in the empirical growth literature (see Durlauf and Johnson 1992, Chatterji 1992 and Quah 1997 for seminal contributions), convergence analyses in the field of energy and environmental economics have found strong support for conditional rather than absolute convergence of energy productivity across countries (see, for example, Miketa and Mulder 2005, Mulder and De Groot 2007, 2012). From this literature it follows that convergence can be understood in terms of levels and growth rates, which translates into a distinction between so-called σ-convergence and β–convergence. The former refers to a decreasing variation of cross-country differences in productivity levels (Kuznets, 1955; Easterlin, 1960a, 1960b; Williamson, 1965; Amos, 1989; Coughlin and Mandelbaum, 1988; Fan and Casetti, 1994; Carolin and Mills, 1996; Bernard and Jones, 1996), while the latter suggests a tendency of countries with relatively low initial productivity levels to grow relatively fast, building upon the proposition that growth rates tend to decline as countries approach their steady state. In this paper we will explore both types of convergence. A log linearization of the Cobb-Douglas framework leads to the standard *β*–convergence specification (Barro and Sala-i-Martin 1992):

$$g_{EP_{i,t}} = c + \beta \ln(EP_{i0}) + \delta X_{it} + \varepsilon_{it} \tag{3}$$

where g_{EP} is the growth rate of EP in country *i* for a given period, EP_{i0} its initial energy productivity level, *c* denotes the intercept, X_{it} denotes country-specific conditional variables, and ε_{it} is a well-behaved error term. The scalar *β* is the measure of the speed of convergence. When $\beta < 0$ and is significantly differently from zero, and δ is a vector whose elements are non-significant, we would claim that we observe absolute β-convergence. Where $\beta < 0$ and is significantly different from zero, and δ is a vector of significant coefficients, we would argue conditional β-convergence holds.

As noted before, in the field of energy studies, sector-based convergence studies have so far not explicitly controlled for spatial dependence in their search for factors that may explain the evolution of cross-country differences in energy productivity. In addition, most of the studies on energy productivity convergence are conducted under the framework of single cross-country regressions, quite unrealistically assuming an identical production function for all the countries in the specified industrial sectors.

In this paper we address these issues by estimating equation (3) for energy productivity growth in manufacturing sectors using a spatial panel data model. It is very likely that the error term contains unobserved country- & industry-specific unobserved factors that affect energy productivity growth. Typically, a panel approach applies fixed- or random-effects models to solve this problem (Islam, 1995). One method for spatial panel models is maximum likelihood (ML) which then allows for correlation across time and space (Kapoor, Kelejian, and Prucha, 2007). The panel data framework makes it possible to correct a possible homogeneous production function bias by allowing for differences of the above-mentioned type in the form of unobserved individual "country effects" and "industry effects" (Islam, 1995). The spatial version of the convergence equation implies that we allow for productivity growth to be affected by the productivity growth of a country's trading partners. Under the panel data structure, this spatial effect enters the convergence regression equation in the form of either a spatial lag of the growth rates (spatial lag model) [3] or a spatial structure in the error (spatial error model), as follows:

$$g_{EP_{ij,t}} = c + \beta \ln\left(EP_{0_{ij,t}}\right) + \delta X_{ij,t} + \rho W g_{EP_{ij,t}} + \varepsilon_{ij,t} \tag{4}$$

$$g_{EP_{ij,t}} = c + \beta \ln\left(EP_{0_{ij,t}}\right) + \delta X_{ij,t} + \varepsilon_{ij,t}, \qquad \varepsilon_{ij,t} = \lambda W \varepsilon_{ij,t} + \tau_{ij,t} \tag{5}$$

where *W* is a trade-flow-based spatial weight matrix, *j* denotes an industry, and other variables are as before.

The choice of spatial weight matrix is mostly based on the researcher's assumption

[3] Standard spatial lag models of convergence have been used in Armstrong (1995); Rey and Montouri (1999); Lopez-Bazo *et al.* (1999); Bivand and Brundstad (2006).

about how regional externalities occur (Li and Haynes, 2011). Authors often represent spillover effects using a contiguity matrix based on adjacency, or a distance matrix based on physical distance among capitals or country centroids. In the case of the EU countries, however, neighboring countries often do not have the same mother tongue and their technological interaction might not be well captured by the pure physical distance. Evidence shows that industries or firms that engage in international trade would be able to raise their productivity by interacting with technologically advanced trading partners (Keller, 2009). This fact could also be true for energy productivity. Therefore, we develop a weights matrix based on international trade flows among EU countries at each individual manufacturing sector as an alternative to the traditional distance-based weight matrix.

Our novel trade flow spatial weight matrix thus defines proximity in terms of trade intensity at the sectoral level, F, and is compiled as:

$$W = \begin{bmatrix} TF_1 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & TF_n \end{bmatrix} \qquad (6)$$

where $TF_j = Row\ Normalized\ [F_j]$, and

$$F_j = \begin{bmatrix} 0 & tf_{21} & \cdots & tf_{v1} \\ tf_{12} & 0 & \cdots & tf_{v2} \\ \vdots & \vdots & 0 & \vdots \\ tf_{1u} & tf_{2u} & \cdots & 0 \end{bmatrix}. \qquad (7)$$

Each element tf_{uv} in F_j is defined as the sum of imports and exports between two countries, *u* and *v* for a specific sector j, where we have *m* countries and *n* sectors, so that $u, v =$

$1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$. The diagonal of the spatial weight matrix (*W*) is composed of row normalized trade flow matrices ($TF_j, j = 1, 2, \ldots, n$) for each detailed manufacturing sectors specified in this paper, and the off-diagonal values are set to zero. The diagonal values of matrix $[F_j]$ are set to zero, indicating that each country does not trade with itself (i.e. we do not consider intra-country regional trade flows). To ask whether energy productivity growth is affected by geography (cf. Verdolini and Galeotti 2011), we also generate the weights matrix described in equation (6) above using inverse distance among country capitals, using the five nearest country neighbors, and by using a contiguity matrix.[4]

3. DATA

The analysis presented in this paper is based on a newly constructed database, developed by Mulder and De Groot (2012), that combines the "EU KLEMS Growth and Productivity Accounts" (O'Mahony and Timmer 2009) with physical energy data from the International Energy Agency (IEA). The EU KLEMS database contains industry-level measures of output, inputs and productivity, derived from a consistent framework of national accounts and supply-and-use tables.[5] The EU KLEMS energy data include expenditure-based intermediate inputs that encompass all energy mining products, oil refining products and electricity and gas products. Using detailed supply-and-use tables, energy expenditures at the industry-level have been deflated by the relative price index of each fuel (energy carrier) and converted to volume indices.[6] Consequently, in contrast to most existing empirical cross-country studies on the

[4] We allow for contiguity to include nations linked by tunnels or bridges.
[5] Based on the growth accounting framework, KLEMS stands for Capital (K), Labor (L), Energy (E), Material (M), Services (S).
[6] Data are freely available at *www.euklems.net*

energy-economy nexus (see, for example, Markandya et al., 2006, Miketa and Mulder, 2005, Mulder and De Groot, 2007, Smulders and De Nooij, 2003), we do not rely on study-specific ad hoc combinations of energy input and economic output measures from different sources – thus avoiding problems in defining sectors consistently across countries.

We measure energy productivity as the ratio of gross value added to intermediate energy input. Value added data have been converted to constant 1997 US$, using a new and comprehensive dataset of industry-specific Purchasing Power Parities (PPPs) for 1997. These PPP series were constructed by the EU KLEMS consortium through double deflation of gross output and intermediate inputs within a consistent input-output framework. The price concepts for gross output (basic prices) and intermediate inputs (purchasing prices) have been harmonized across countries. To allow for comparing energy input levels across countries and across sectors the EU KLEMS energy volume index numbers have been matched with IEA final energy consumption data in kilo tonnes of oil equivalent (ktoe).[7] Guided by the sectoral classification that the IEA uses in its Energy Balances, we did this for the 10 manufacturing sectors distinguished in this paper – see Table 1.

<<Insert Table 1>>

Our cross-country energy productivity convergence analysis covers the period 1995-2005, and includes 12 EU-15 countries (Austria, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Portugal, Spain, Sweden and the United Kingdom) and 4

[7] This matching has been done according to the following simple two-step procedure. First, for the year 2005 EU KLEMS energy volume index numbers have been matched with IEA final energy consumption data in kilo tonnes of oil equivalents (ktoe). Second, using EU KLEMS energy input volume indices, energy consumption in ktoe has been (re-)calculated for earlier years. See for more details Mulder and De Groot (2012).

new EU member states situated in Eastern Europe (Czech Republic, Hungary, Poland, Slovakia). While some energy data goes back to 1970, we do not have complete data until 1995. Given that spatial panels require a balanced panel dataset, the selection of testing periods for convergence among specified EU countries is confined to the period of 1995-2005. Sample details are presented in Table 2.

<<Insert Table 2>>

Trade flow data including both imports and exports for each industry sector among the 16 EU partner countries are retrieved from 2006 STAN Bilateral Trade Database,[8] and the latest year's data (2004) are taken to estimate the benchmark level of trade relations among the EU countries at detailed sectoral level.

Selection of Conditional Variables

In our regression approach, we first estimate a simple unconditional energy convergence equation, where we only control for initial energy productivity level and spillovers from trade partners. We use both random and a series of fixed effects, where the latter approach controls for time-invariant industry and country characteristics. We next estimate a conditional convergence equation, where we control for a number of specific country and industry-specific characteristics to observe if our estimates of convergence persist and whether trade continues to play a role in determining energy productivity growth. Last, we explore the factors that affect energy productivity convergence. Specifically, we ask how trade affects energy

[8] STAN is OECD's STructural ANalysis Database. We use 2004 because earlier years had less complete sector-specific trade-flow data.

productivity by considering the effect of country specialization and trade intensity. We also consider various characteristics of the country's energy market and ask how these factors affect convergence.

We first control for trade intensity by country by industry. Trade intensity measures the ratio of sector imports plus exports to gross output for each sector in each country to control for the dependence of that industry on trade. We also include the degree of specialization by estimating the Krugman Index for these manufacturing sectors (please see Section 4 for more details)

As noted above, we also speculate that characteristics of the domestic energy market may affect a country's incentives or ability to adopt energy technology. One driver of energy productivity is clearly energy price. Price information on energy use for each country is calculated as sector-specific energy expenditure in 1995 and 2000 (in constant 1997 US$) divided by physical energy consumption (in ktoe). Energy expenditure (in US$) and physical energy consumption (in ktoe) are both retrieved from EU KLEM database, as described above. Because we were concerned that specific price might be endogenous to energy productivity levels, we also use a dummy variable to split our sample countries into those higher and lower than the median price in each time period. One alternative hypothesis is that trade facilitates convergence in energy prices, which in turn facilitates energy productivity convergence. We test this by running convergence in energy prices over the same time period.

The composition of a country's energy use may also affect its ability to adopt new technologies. We control for the percent of energy consumption by country by sector that comes from gas and electricity, as compared to coal and oil. We include this control variable to account for the fact that changes in energy mix may be an important source of aggregate energy productivity developments, because some energy types, such as natural gas and electricity, are more efficient than others, such as coal and oil, in terms of available energy (see, for example, Berndt 1978, Cleveland et al. 2000, Kaufmann 2004).

We also control for exogenous factors affecting energy demand. Specifically, we include the logarithm of the sum of heating and cooling degree days (HDDs and CDDs,) to capture weather-driven energy demand (see equation 22). A "degree day" is a measure of the average temperature's departure from a human comfortable level of 18 °C (65 °F). HDDs and CDDs are both calculated in a cumulative fashion. Data on HDDs and CDDs are collected from the Climate Analysis Indictors Tool (CAIT) at World Resource Institute (Baumert and Selman, 2003).

Last, we include a measure of environmental regulation. Our choices to adopt a dynamic measure of environmental stringency were severely limited, as most environmental regulatory indices at the country level are either not available for all countries in our sample, or difficult to compare across countries because of differences in definitions or insufficient within-country variation. For these reasons, several authors have used lead content in gasoline to measure regulatory stringency for other purposes (see, for example, Damania et al. 2003, Hilton and Levinson 1998, Soest et al., 2006). This consumptive-based measure is a signal of environmental stringency, because countries with relatively strict environmental policies should allow lower lead content per gallon of gasoline, given that lead emissions are precursors to harmful local air pollutants. Damania et al. (2003) have shown that lead content in gasoline is highly correlated in the right direction with several alternative methods to measure international differences in environmental compliance costs, including public environmental R&D expenditures as a proportion of GDP, membership in environmental organizations and a production-based index developed by Dasgupta et al. (1995) and Eliste and Fredriksson (2002) that is derived from survey-based country reports for the 1992 United Nations

Conference on Environment and Development in Rio on existing environmental regulations. We collected data on grams of lead content per gallon of gasoline (LEAD) from the "worldwide gasoline survey" published annually by OCTEL (1983-1995), and this paper uses the data from year 1995. The data series show considerable cross-country differences, with Hungary having the highest lead content per gallon of gasoline of our sample; this is about 18 times higher than in Sweden, the country in our sample with the lowest variance (0.15 versus 0.008 gram).

A variety of energy policies have been applied to the manufacturing sector over this time. During the 1990s, voluntary agreements for energy efficiency improvement and reduction of energy-related GHG emissions by industry were dominant (Price, 2005). The first voluntary agreements were the Long-Term Agreements on Energy Efficiency in the Netherlands, the Danish Agreement on Industrial Energy Efficiency, and the Declaration of German Industry on Global Warming Prevention.[9] Since 2000, a number of countries began to convert voluntary agreements into mandatory regulations. For instance, in 2002, France replaced its initial 1996 voluntary program with a new program that includes a penalty for non-compliance and allows for emission trading. Other countries have adopted a second generation of energy agreements, such as Finland, Germany, and The Netherlands, all of which either increased the number of incentives in place to reduce energy use or added penalties

[9] In short, these voluntary agreements where only partially effective. For example, in The Netherlands in the period 1989–1997, on average, between a quarter and a half of the energy savings in the Dutch Manufacturing industry can be attributed to the policy mix of Long-Term Agreements (LTAs) and supporting measures. Furthermore, under LTAs the prevention of free riding was fairly effective, the LTA's were flexible over time and did actually have an impact on firm behavior. But, at the same time, in The Netherlands more than half of the LTA sectors were lagging behind the agreed rate of intensity decrease. In Sweden the administrative costs and search costs turned out to be high and the impact on innovation and networking among firms was low. Also, across countries, institutional environments marked by fragmentation of power and open access in policymaking reduced regulatory credibility and thus hampered the implementation of LTAs. For more details see, amongst others, Delmas and Terlaak (2002), Farla and Blok (2002), Johannsen (2002), Rietbergen et al. (2002).

(Price, 2005). These changes largely occurred after 2000 and therefore, it is worthwhile to test the policy effects on energy productivity growth rates for the two periods (1995-2000 and 2000-2005).

4. ENERGY PRODUCTIVITY AND TRADE IN EU

We start our analysis with presenting in Table 3 the average annual growth rates of energy productivity across industrial sectors for three clusters of European countries and for two different time periods: 1980–2005 and 1995–2005.[10] These data originate from Mulder (2015), but in contrast we focus our analysis on 16 European Union countries. The statistics show a pattern of rising overall energy productivity, across all country clusters with increases being relatively strong in the period after 1995. The underlying data reveal a remarkable slowdown in energy productivity increase between 1980 and 1995. Evidently, this trend is linked to relatively low and decreasing energy prices since the mid-1980s, after a period of high prices induced by the energy crises of the 1970s and subsequent energy efficiency improvements (IEA 2004).

<<Insert Table 3>>

As regards to energy productivity changes within manufacturing subsectors, Table 3 shows that in most manufacturing sectors, energy productivity growth rates are positive, with the sectors Food, Wood and Basic Metals as notable exceptions. In Western Europe (EU8), after

[10] EU8: Denmark, Finland, United Kingdom, Austria, Belgium, France, Germany, Spain; EU16: Austria, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Portugal, Spain, Sweden and the United Kingdom, Czech Republic, Hungary, Poland, Slovakia; EU4: Czech Republic, Hungary, Poland, Slovakia. See Section 4.

1995, energy productivity growth rates are especially high in the sectors Chemicals and Machinery. In Eastern Europe (EU4) the picture is more diverse, with negative growth rates of energy productivity in various sectors, especially in Chemicals, but with very high energy productivity growth rates in the sectors Non-Metallic Minerals, Machinery and Transport Equipment.

Next, we present the evolution of cross-country differences in manufacturing energy productivity over time, measured by the standard deviation of the log of energy productivity levels across EU member states in Figure 1A. As mentioned before, decreasing cross-country variance in energy productivity levels is taken as evidence for so-called σ-convergence. Reported first by Mulder (2015), the Figure shows that until about 1997 manufacturing energy productivity levels across EU member states were clearly diverging. However, as of the late 1990s we see a striking and strong break in the trend, with manufacturing energy productivity levels beginning to rapidly converge across countries in the EU.[11]

<<Insert Figure 1A and Figure 1B>>

To further understand this break in productivity trends, in Table 4 we provide a decomposition of the *σ*–convergence trends. The 'actual' numbers refer to observed energy productivity levels, whereas 'common structure' refers to hypothetical energy productivity levels that correct the observed levels for cross-country differences in sector structure.[12] In other words, the

[11] Underlying data reveal that the trend-break in aggregate manufacturing σ-convergence (Figure 1A) is largely caused by strong cross-country convergence of energy intensity levels in the sectors Food and Basic Metals, and further enhanced by convergence in the sectors Pulp & Paper, Textiles and Transport Equipment (EU 16 sample). See Mulder (2015) for more details.
[12] Using standard index decomposition techniques ((LMDI), it is calculated as the aggregate product of actual energy intensity levels within each manufacturing subsector and a common sector structure.

'common structure' energy productivity trends define what a country's productivity trends would have been if it had the same manufacturing sector structure as all other countries. From the left-hand side of the Table it can be concluded that over time an increasing part of cross-country differences in manufacturing energy intensity levels can be attributed to cross-country variation in sector structure. For example, for the cluster of EU8 countries, in 2005, the cross-country variation in sector structure explains about 20% of cross-country manufacturing energy productivity differences, in comparison to 3% in 1980. The right-hand side of Table 6 shows that across the various groups of countries, changes in the sector structure have encouraged cross-country divergence of manufacturing energy productivity levels, especially in the period 1980-1995. As noted by Mulder (2015), these findings suggest that the shift towards rapid cross-country convergence, as shown in Figure 1A, is caused by efficiency improvements in lagging countries that more than offset the diverging impact of increasing international differences in sector structure.

<<Insert Table 4>>

As noted in the introduction, the role of economic structure in aggregate energy productivity dynamics is related to international trade patterns, given the fact that trade flows influence the structure of economies through its impact on (changing) production patterns. Following Mulder (2015), we therefore present in Figure 1B the evolution of cross-country variation in specialization patterns across EU countries. This done on the basis of the Krugman specialization index (Krugman 1991), that measures the extent to which a country's production patterns differ from those of a comparison group of countries (EU8 and EU16). It runs from zero if the country produces the same goods in the same proportions as the group of countries, to two if they produce only different goods.[13] Figure 1B then shows the evolution over time of the standard deviation of this country-specific specialization index across the group of countries. From Figure 1B it can be concluded that that within the EU, measured in terms of output (value added), the differences in production patterns (specialization) across countries have increased substantially since 1992. In other words: we observe increasing production heterogeneity in the EU.

Mulder (2015) has hypothesized that increasing trade is the likely source of both the increasing cross-country variation in production patterns (Figure 1B) and the almost parallel (2-year lagged) decreasing cross-country variation in energy productivity levels (Figure 1A). Increasing market integration presumably facilitated not only specialization and fragmentation of production processes across EU member states but also knowledge-spillovers, resulting in convergence of energy productivity (Figure 1A). Thus, apparently, the latter mechanism has (by far) outweighed the potential impact of specialization on divergence of manufacturing energy productivity through divergence in production structure (Grossman and Helpman 1991). This idea finds support in Duro et al. (2010) and Mulder and De Groot (2012), who show that aggregate convergence patterns are almost exclusively caused by convergence of within-sector energy productivity levels (i.e. a 'technology effect'), while frequently undermined by changes in the sectoral composition of economies.

5. REGRESSION RESULTS

Inspired by the stylized facts presented in the previous section, we explore in this section the

[13] Technically: let s_j be the share of Manufacturing sector j in the country's total Manufacturing value added and s_j^* be that share in the group, the index is then defined as $K=\Sigma j|s_j - s_j^*|$.

role of trade in explaining manufacturing energy productivity growth by means of a spatial panel regression based on Kapoor et al. (2007), using the code developed by Millo and Piras (2012). We first use a Moran's I test to ask whether energy productivity and energy productivity growth is correlated based on trade flows and geography. We find energy productivity levels and growth in one industry and country to be significantly correlated with that of the country's neighbors. This correlation holds regardless whether neighbors are defined by trade flows or by geography, with the exception that energy productivity growth does not appear spatially correlated using geographic weights generated by inverse distance. These results lead us to control for trade flows and later for geography in our convergence regressions.

Next, we explore whether to use a spatial lag or spatial error model. In other words, we want to discern whether manufacturing energy productivity growth of one country directly affects the growth of manufacturing energy productivity of its neighbor, or whether the unexplained portion of neighboring growth rates are correlated with each other. When we allow for both spatial error and spatial lags in the same models, we find significant spatial correlation in the error term, but never significant spatial lags. This result holds whether we use the trade flow definition of neighbor or our geographically-derived spatial weights. Thus, we determine that the spatial error model is the most appropriate for our analysis.

The results for the spatial error models with random effects are reported in Table 5 using our trade-based weights. In Model 1 we estimate the absolute convergence model, not controlling for any other covariates. In Model 2, we control for the fact that the metals sector in Hungary appears to be an outlier in terms of energy productivity. Once we control for this particular outlier, we observe significant energy convergence. In Models 3 and 4 (columns 3 and 4 in Table 5), we include first industry, then industry and country fixed effects to control for an increasing number of time-invariant factors. One of the first things to note is that in virtually all models, our measure of convergence, β is negative and significantly different from zero, where β is the coefficient of $log(EP_0)$). Specifically, we observe estimated rates of convergence that range from -0.02 to -0.07, implying that a one percent decrease in initial energy productivity leads to a 2 to 7 percent increase in the rate of energy productivity growth.

Next we explore the effect of trade on convergence. We first compare estimates of the spillover effects driven by trade versus proximity by looking at the spatial correlation of the error term (ϱ), shown in the second row of Table 5. The degree of correlation is positive and highly significant using connections defined by trade flows. Specifically, using the results from the spatial error model, between 30 and 41% of the unexplained portion of the growth in manufacturing energy productivity is explained by positive spillovers from trade partners.

We next explore which regions and industries exhibit this convergence. Results of region and industry interaction terms are presented in Table 6. As can be seen in the first column of Table 5, convergence is largely driven by convergence within western European member states, which may make sense given the early time-frame of our data relative to eastern country accession. Thus, eastern European industries may not have had time yet to transition their industries to facilitate adoption of improved energy efficiency. We also observe that, as expected, western European countries have a higher level of manufacturing energy productivity in general. In the second column of Table 6, we observe significant convergence in each manufacturing sector, with the exception of metals (sector 7). In particular, Sector 1 (Food, Beverages, and Tabacco), Section 2 (Textiles, Leather, and Footwear), and Sector 9 (Transportation Equipment) have substantially higher rates of convergence than the other sectors.

Next, we estimate a conditional convergence model, controlling for various country and industry characteristics that might affect energy productivity in manufacturing. The results for this model are presented in Table 7. We first ask whether trade directly affects energy productivity growth. When we consider trade intensity of each country-industry pair, we find consistent evidence that the more trade dependent the country and industry, the higher the rate of growth of energy efficiency in Manufacturing. We find little effect on energy productivity growth of most energy supply and demand factors, such as source of energy, whether the country faces high energy prices or environmental regulations. The only factor that appears to affect energy efficiency growth is the number of heating and cooling degree days, which positively affect energy efficiency. In all cases, however, using the conditional convergence equation, our estimates of energy efficiency convergence remain significant and consistent with the unconditional convergence results, ranging from -0.04 to -0.06.

We then ask what factors affect convergence in manufacturing energy productivity. We first ask whether a country's trade dependence increases or decreases convergence. As noted earlier, one might anticipate that trade-induced specialization might limit the potential for energy convergence, while trade-induced competition may induce industries to reduce costs, including those from energy. We observe clear results that the more trade dependent the industry by country pair, the greater the energy convergence. Specialization neither induces nor impairs convergence. These results are presented in Table 8.

While characteristics of the domestic energy market have little effect on electricity productivity growth, they do influence convergence. Those countries with higher priced electricity show a faster rate of energy convergence.[14] Further, countries whose energy comes more from gas and electricity also have faster convergence rates, perhaps reflecting these fuels' flexibility.

[14] We find that energy prices themselves converge over time, but this convergence is not affected by trade. Thus, it does not appear that trade speeds the convergence of energy prices, while it does speed the convergence of energy productivity.

Geographic weights

In the above results, we measured connections among countries using sector-specific trade flows. One might be concerned that these trade flows are merely picking up geographic proximity, and thus spillovers in productivity may primarily be driven by space. To explore this hypothesis, we generate weights using various measures of geography. We then run our unconditional convergence model using increasing fixed effects with three geographic weights to ask whether these measures of geography explain correlation in the unexplained portion of energy productivity growth. While distance between capitals generally has no effect, contiguity and five nearest neighbor-based weights explain a portion of the error term, although largely less than is explained in the trade model. Results of these regressions are presented in Tables 10a, 10b and 10c.

To test whether these geographic measures merely mask the effect of trade, we generate a new weights matrix with the residuals from an OLS regression of trade flows on the five nearest neighbors, and then another set of residuals from the regression of trade flows on contiguity. If trade has an effect over and above geography, we should see the weights matrix generated from these residuals explain a significant portion of the variation in manufacturing energy productivity growth. One constraint is that all elements of the weights matrix must be non-negative, thus we linearly transform the matrix elements by adding a constant equal to the smallest error term, to force all error terms to be non-negative. The results using these two weights matrices are presented in Tables 11a and 11b. As can be seen in the results, while the correlation is small (ϱ=0.003) these residual weights explain a significant portion of the correlation between manufacturing energy productivity growth. Further, unlike either the direct trade flow weights or the geographic weights, the amount by which industries and countries trade with each other over and above that explained by geography appears to directly explain productivity growth in the form or a spatial lag. (Estimates of the degree of spatial correlation in the residual, rho, and the estimate of the spatial lag, lambda, are presented in Table 10). The first three columns represent the spatial error and lag estimates using the weights generated by the residual trade flows after stripping out the effect of the five nearest neighbors; the last three columns use weights generated from trade flows after accounting for contiguity). Thus, while not strictly conclusive, these results suggest that trade flows can facilitate spillovers in energy productivity growth.

6. CONCLUSIONS

In this paper we ask whether energy productivity in manufacturing has converged in Europe and whether the growth in energy productivity is enhanced by trade. The existing literature does not provide us with a clear understanding of the role of trade as a determinant of cross-country variation in energy productivity over time. On the one hand, by accelerating knowledge diffusion and equalizing factor prices, trade may help reduce productivity gaps among countries. On the other hand, by encouraging international specialization, trade could lead to divergence of factor productivity via shifts in sector structure or changes in the terms of trade.

Unlike most earlier work, we use detailed sector-specific measures of energy productivity. Moreover, we ask whether spillovers have been driven by trade flows instead of geography. We construct a novel trade flow spatial weight matrix at the sector level, to define proximity in our spatial econometric analysis in terms of trade intensity. The underlying idea is that trade rather than geographical proximity per se stimulates energy productivity growth in lagging countries because it facilitates diffusion of knowledge about state-of-the-art energy efficient technologies, contributes to factor price equalization and increases competition and thus the need to increase efficiency.

Like earlier work by Miketa and Mulder (2005), Mulder and De Groot (2007, 2012) and Mulder (2015), we find clear evidence of convergence in energy productivity. Unlike earlier work (Mulder et al. 2011) we find that the spillovers in manufacturing energy productivity arise from trade, and that trade continues to explain positive spillovers over and above those explained by geographical proximity. More specifically, about 30 to 40% of the unexplained portion of growth in manufacturing energy productivity is explained by positive spillovers from trade partners. In general, except for the number of heating and cooling degree days, we find little effect on manufacturing energy productivity growth of the most obvious energy supply and demand factors, such as the source of energy, whether the country faces high energy prices or environmental regulations. In regards to the rate of convergence, we find that trade intensity increases convergence while specialization neither induces nor impairs cross-country convergence of manufacturing energy productivity. Countries with higher priced electricity and countries whose energy comes more from gas and electricity also show a faster rate of energy convergence in manufacturing.

While some specifications of geographic weights do explain a fraction of the unexplained portion of manufacturing energy productivity growth, this effect might be driven by the fact that geography also explains trade flows. Therefore, we generate residual trade flows after stripping away the effect of geography, and find that these residuals explain a significant portion of productivity growth. Thus, in contrast to concerns that trade may spur a 'race to the bottom', we find that promoting trade may help stimulate energy efficiency improvements across countries. More generally, our work raises the question as to whether geography is the appropriate definition of neighbor in the economic context, or whether contiguity or distance is merely capturing a more important driver of convergence: trade.

Because we focus on energy productivity convergence in manufacturing industries, our analysis misses other important drivers of energy use, such as transportation. Thus, in as much as trade may induce greater goods transport, we would miss this effect (Hummels 2008). Second, because our data end by 2005, we cannot explicitly test the effect of the EU cap and trade scheme in energy, which might have further induced energy productivity and facilitated convergence

Further work is needed to explore the detailed mechanism through which trade affects energy productivity. We see at least three possible routes for this effect. First, by enhancing competition between exporters and import-competing sectors, trade may force the import-competing industries to become more productive, including in their energy use. Second, specialization might cause industries to diverge, making it more difficult to adopt technologies from trading partners. Third, the Melitz model predicts that higher-productivity firms are more likely to engage in trade, implying that instead of increasing the energy productivity of all firms, trade may allow those firms that are already more productive to expand, and thus increasing overall industry productivity. While we cannot explicitly test these hypotheses in our data, we do find evidence that increased specialization is associated with higher manufacturing energy productivity which might lend credence to the first or third option. In either case, our results indicate that unlike predictions from the pollution haven hypothesis, trade may facilitate the adoption of energy productivity enhancements, reducing the use of energy in manufacturing production.

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Tables and Figures

Table 1. Sector classification

	Sector	NACE rev1 code
0	MANUFACTURING	15t22, 24t37
1	Food, Beverages and Tobacco	15t16
2	Textiles, Leather and Footwear	17t19
3	Wood and Cork	20
4	Pulp, Paper, Printing and Publishing	21t22
5	Chemicals	24
6	Non-metallic Minerals	26
7	Basic Metals	27
8	Machinery	28t32
9	Transport Equipment	34t35
10	Non-Specified Industry	25,33,36t37

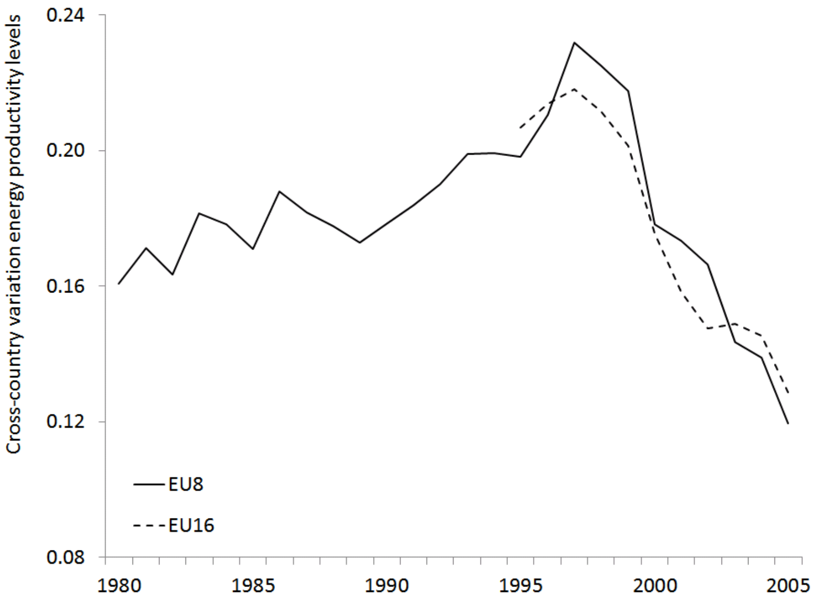
Table 2. Countries and samples used in this study

	Country	Code	1970-2005	1980-2005	1995-2005	
				EU8	EU16	EU4
1	Denmark	DNK	X	X	X	
2	Finland	FIN	X	X	X	
3	United Kingdom	UK	X	X	X	
4	Austria	AUT		X	X	
5	Belgium	BEL		X	X	
6	France	FRA		X	X	
7	Germany	GER		X	X	
8	Spain	SPA		X	X	
9	Italy	ITA			X	
10	Netherlands	NLD			X	
11	Portugal	PRT			X	
12	Sweden	SWE			X	
13	Czech Republic	CZE			X	X
14	Hungary	HUN			X	X
15	Poland	POL			X	X
16	Slovakia	SVK			X	X

Table 3. Growth rates and % change in cross-country variation of energy productivity

		Energy productivity growth rates			
		EU8		EU4	EU16
Sector	NACE rev1 code	1980 – 2005	1995 – 2005	1995 – 2005	1995 – 2005
MANUFACTURING		1.3	1.5	5.2	1.6
Food, Beverages and Tobacco	15t16	0	-0.2	2.7	-0.4
Textiles, Leather and Footwear	17t19	0.3	0.3	3	0
Wood and Cork	20	0.9	-1.6	-1.7	0.5
Pulp, Paper, Printing and Publishing	21t22	0.6	0.9	-0.3	0.3
Chemicals	24	3.6	3.2	-5.2	2.2
Non-metallic Minerals	26	2.1	0.3	11.4	1.8
Basic Metals	27	2	-0.1	-0.2	-0.2
Machinery	28t32	0.8	2.9	9.8	2.9
Transport Equipment	34t35	1.2	1.5	10.5	1.7
Non-Specified Industry	25,33,36t37	1.2	0.9	6.7	0.8

Source: Mulder (2015).



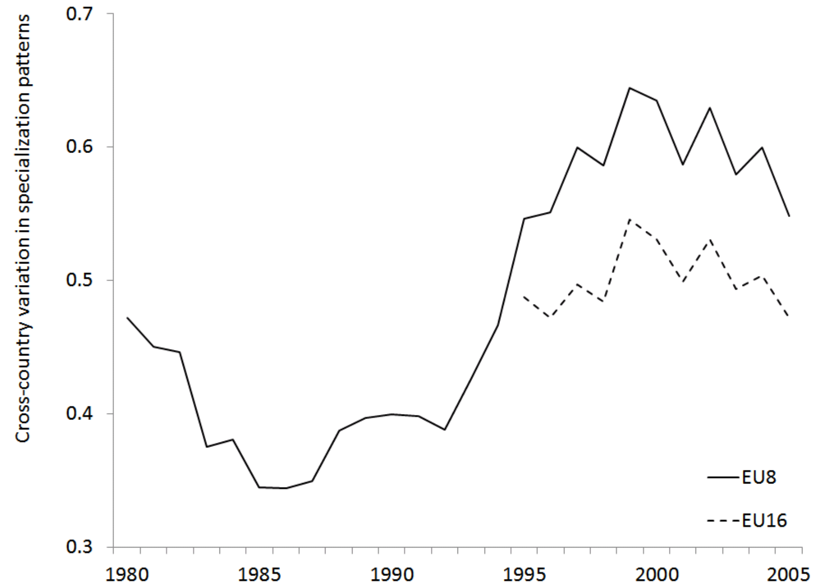


Figure 1A

Figure1B

Figure 1A: σ- convergence analyses of energy productivity.

Figure 1B: σ -convergence analysis of Krugman specialization index.

Tabel 4. Decomposition of σ–convergence trends

Degree of cross-country variation*					% Change of cross-country variation				
Year	Sample	Actual	Common Structure	% Explained by variation in structure	Period	Sample	Actual	Common Structure	Contribution structure
1980	EU8	0.16	0.16	3%	1980-2005	EU8	-26	-39	13
1995	EU8	0.20	0.15	22%	1980-1995	EU8	23	0	23
	EU16	0.21	0.18	12%					
2005	EU8	0.12	0.10	20%	1995-2005	EU8	-40	-38	-2
	EU16	0.13	0.11	18%		EU16	-38	-42	4

* Measured as standard deviation of log(energy productivity). Source: Mulder (2015).

Table 5. Main results of unconditional convergence model

	1	2	3	4
ln(energy productivity$_0$)	-0.022	-0.050***	-0.069***	-0.036**
	(0.016)	(0.019)	(0.020)	(0.017)
ρ	0.419***	0.444***	0.319***	0.301***
	(0.092)	(0.089)	(0.104)	(0.105)
Hungarian metals FE	no	yes	yes	yes
Industry FE	no	no	yes	yes
Country FE	no	no	no	yes

Spatial standard errors in parentheses
***, **, * signify different from zero at the 99%, 95% and 90% level of significance respectively.

Table 6. Convergence by region and industry

	1	2
East	0.449	
	(0.277)	
West	0.542***	
	(0.202)	
ln(energy productivity$_0$) × East	-0.032	
	(0.031)	
ln(energy productivity$_0$) × West	-0.068***	
	(0.021)	
ln(energy productivity$_0$) × Industry1		-0.393**
		(0.153)
ln(energy productivity$_0$) × Industry2		-0.354***
		(0.115)
ln(energy productivity$_0$) × Industry3		-0.107*
		(0.060)
ln(energy productivity$_0$) × Industry4		-0.098
		(0.065)
ln(energy productivity$_0$) × Industry5		-0.145
		(0.107)
ln(energy productivity$_0$) × Industry6		-0.390***
		(0.150)
ln(energy productivity$_0$) × Industry7		0.006
		(0.024)
ln(energy productivity$_0$) × Industry8		-0.062
		(0.089)
ln(energy productivity$_0$) × Industry9		-0.466***
		(0.077)
ln(energy productivity$_0$) × Industry10		-0.041
		(0.070)
ρ	0.260***	0.263***
	(0.108)	(0.109)
Hungarian metals FE	yes	yes
Industry FE	yes	yes
Country FE	no	no

Spatial standard errors in parentheses

***, **, * signify different from zero at the 99%, 95% and 90% level of significance respectively.

Table 7. Conditional Convergence; Controlling for Trade and Energy Characteristics

	1	2	3	4
ln(energy $productivity_0$)	-0.048**	-0.035**	-0.043**	-0.059***
	(0.019)	(0.016)	(0.018)	(0.018)
Trade intensity	15.633*	18.577*		
	(8.148)	(9.864)		
Krugman specialization index	0.087	-0.034		
	(0.134)	(0.411)		
High priced energy indicator			-0.005	-0.001
			(0.042)	(0.042)
Gas and electric share			0.169*	0.126
			(0.086)	(0.086)
Heating and cooling degree days			0.249*	0.258*
			(0.150)	(0.145)
Lead			0.605	0.703
			(1.182)	(1.143)
East			-0.153	-0.134
			(0.140)	(0.134)
ρ	0.424***	0.304***	0.397***	0.248**
	(0.091)	(0.105)	(0.093)	(0.110)
Hungarian metals FE	yes	yes	yes	yes
Industry FE	no	yes	no	yes
Country FE	no	yes	no	no

Spatial standard errors in parentheses
***, **, * signify different from zero at the 99%, 95% and 90% level of significance respectively.

Table 8. Characteristics that affect convergence

	1	2	3	4
ln(energy productivity$_0$)	0.014	0.051	-0.050**	-1.279**
	(0.041)	(0.043)	(0.023)	(0.545)
Trade intensity	193.326***			
	(56.099)			
Krugman specialization index	-0.190			
	(1.025)			
Gas and electric energy share		1.562***		
		(0.675)		
High price energy indicator			0.697**	
			(0.310)	
Heating and cooling degree days				-1.050*
				(0.585)
ln(energy productivity$_0$) × Trade intensity	-19.991***			
	(6.328)			
ln(energy productivity$_0$) × Specialization index	0.019			
	(0.104)			
ln(energy productivity$_0$) × Gas and electric share		-0.165***		
		(0.074)		
ln(energy productivity$_0$) × High price electricity			-0.074**	
			(0.035)	
ln(energy productivity$_0$) × Heating and cooling degree days				0.149**
				(0.067)
ρ	0.300***	0.279***	0.316***	0.283***
	(0.104)	(0.109)	(0.104)	(0.107)
Hungarian metals FE	yes	yes	yes	yes
Industry FE	yes	yes	yes	yes
Country FE	yes	yes	no	no

Spatial standard errors in parentheses

***, **, * signify different from zero at the 99.9%, 99% and 95% level of significance respectively.

Table 9a. Unconditional convergence with distance weights

	1	2	3	4
ln(energy productivity$_0$)	-0.015	-0.035**	-0.072***	-0.037**
	(0.016)	(0.018)	(0.020)	(0.017)
ρ	0.077	0.095	-0.050	0.080
	(0.074)	(0.073)	(0.077)	(0.077)
Hungarian metals FE	no	yes	yes	yes
Industry FE	no	no	yes	yes
Country FE	no	no	no	yes

Spatial standard errors in parentheses
***, **, * signify different from zero at the 99%, 95% and 90% level of significance respectively.

Table 9b. Unconditional convergence with five nearest neighbor weights

	1	2	3	4
ln(energy productivity$_0$)	-0.025	-0.046**	-0.071***	-0.037**
	(0.017)	(0.019)	(0.020)	(0.017)
ρ	0.358***	0.366***	0.269***	0.253***
	(0.077)	(0.077)	(0.085)	(0.000)
Hungarian metals FE	no	yes	yes	yes
Industry FE	no	no	yes	yes
Country FE	no	no	no	yes

Spatial standard errors in parentheses
***, **, * signify different from zero at the 99%, 95% and 90% level of significance respectively.

Table 9c. Unconditional convergence with contiguity weights

	1	2	3	4
ln(energy productivity$_0$)	-0.026	-0.044**	-0.072***	-0.038**
	(0.017)	(0.019)	(0.020)	(0.017)
ρ	0.259***	0.257***	0.189***	0.172***
	(0.060)	(0.060)	(0.062)	(0.062)
Hungarian metals FE	no	yes	yes	yes
Industry FE	no	no	yes	yes
Country FE	no	no	no	yes

Spatial standard errors in parentheses
***, **, * signify different from zero at the 99%, 95% and 90% level of significance respectively.

Table 10a. Unconditional convergence with weights from residuals of trade regressed on five nearest neighbors

	1	2	3	4
ln(energy productivity$_0$)	-0.010	-0.029	-0.069***	-0.036**
	(0.016)	(0.018)	(0.020)	(0.017)
ρ	0.003**	0.003**	0.003**	0.003**
	(0.001)	(0.001)	(0.002)	(0.001)
Hungarian metals FE	no	yes	yes	yes
Industry FE	no	no	yes	yes
Country FE	no	no	no	yes

Spatial standard errors in parentheses
***, **, * signify different from zero at the 99%, 95% and 90% level of significance respectively.

Table 10b. Unconditional convergence with weights from residuals of trade regressed on contiguity

	1	2	3	4
ln(energy productivity$_0$)	-0.010	-0.029	-0.069***	-0.036**
	(0.016)	(0.018)	(0.020)	(0.017)
ρ	0.003**	0.003**	0.003**	0.003**
	(0.001)	(0.002)	(0.002)	(0.001)
Hungarian metals FE	no	yes	yes	yes
Industry FE	no	no	yes	yes
Country FE	no	no	no	yes

Spatial standard errors in parentheses
***, **, * signify different from zero at the 99%, 95% and 90% level of significance respectively.

Table 11. Spatial lag regression with weights from trade flows over and above geography

	Weights from residuals of trade flows regressed on five nearest neighbors			Weights from residuals of trade flows regressed on contiguity		
	1	2	3	4	5	6
ρ	0.000	-0.027	-0.019	0.000	-0.051	-0.042
	(0.002)	(0.022)	(0.024)	(0.003)	(0.038)	(0.045)
λ	0.003*	0.005***	0.005***	0.003*	0.005***	0.006***
	(0.002)	(0.000)	(0.001)	(0.002)	(0.000)	(0.000)
Hungarian steel	yes	yes	yes	yes	yes	yes
Industry FE	no	yes	yes	no	yes	yes
Country FE	no	no	yes	no	no	yes

Spatial standard errors in parentheses
***, **, * signify different from zero at the 99%, 95% and 90% level of significance respectively.