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Energy Efficiency and Industrial Output: The Case of the Iron and Steel Industry

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Summary

The iron and steel industry is one of the most carbon emitting and energy consuming sectors in Europe. At the same time this sector is of high economic importance for the European Union. Therefore, while public environmental and energy policies target this sector, there is political concern that it suffers too much from these policy measures. Various actors fear a policy-induced decline in steel production, and possibly an international reallocation of production plants. This study analyzes the role that input prices and public policies may play in attaining an environmentally more sustainable steel production and how this - in turn - affect total steel output. As we find out for examples of major European steel producing countries, a kind of rebound effect of energy-efficiency improvements in steel production on total steel output may arise.

Keywords: Energy Efficiency, Iron And Steel Industry, Environmental Protection, Rebound Effect

JEL Classification: L51, L61, Q43, Q50

The authors are solely responsible for the contents which do not necessarily represent the opinion of their institutions. Florens Flues and Stefan Vögele are grateful for funding provided by the Helmholtz Alliance Energy Trans and the hospitality of BC3.

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Energy Efficiency and Industrial Output: The Case of the Iron and Steel Industry

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Abstract

The iron and steel industry is one of the most carbon emitting and energy consuming sectors in Europe. At the same time this sector is of high economic importance for the European Union. Therefore, while public environmental and energy policies target this sector, there is political concern that it suffers too much from these policy measures. Various actors fear a policy-induced decline in steel production, and possibly an international reallocation of production plants.

This study analyzes the role that input prices and public policies may play in attaining an environmentally more sustainable steel production and how this - in turn - affect total steel output. As we find out for examples of major European steel producing countries, a kind of rebound effect of energy-efficiency improvements in steel production on total steel output may arise.

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1 Introduction

Reduction in CO₂ emissions and energy consumption are two of the main objectives of the EU's energy policy. Highly ambitious objectives like a reduction in CO₂ emissions by 80-95% up to 2050 as set by the European Council (European Commission, 2011) and the German government (Bundesregierung, 2010) will significantly impact the energy supply system as well as the economy as a whole. Especially energy intensive sectors like the iron and steel industry will be affected by CO₂ reduction measures which may result in additional (cost) pressure. Taking into account high competition levels in national and international markets, increasing cost could result in less domestic production. However, politicians seek not only to reduce CO₂ emissions but also to sustain domestic value creation of these industries.

Using the example of the iron and steel industry we analyze the factors which determine changes in specific energy consumption of production by taking changes in cost factors, including energy policy, into account. Specific energy consumption refers to the ratio of total energy consumption to production volume. A special focus is paid to the question if a decline in specific energy consumption goes hand in hand with de- or increased production levels. The iron and steel sector has been chosen as an example for analyzing impacts of energy politics on industry, because of its high share in European CO₂ emissions and its high level of energy demand (EEA, 2013; Eurostat, 2012).¹ Another reason is the high topicality of European steel policy. In June 2013, the European Commission proposed an action plan for the European steel industry (European Commission, 2013). This document is remarkable as it is the first time since the Davignon Plan of 1977 that the European Commission proposed a comprehensive action plan for steel.² The new action plan observes the need to stimulate growth in the EU steel sector, cut costs and increase innovative, sustainable steel production. Our analysis may reveal important recommendations pursuing the objectives of the EU action plan.

In several studies the impacts of non-financial barriers on the deployment of energy efficient technologies have been pointed out (e.g. (ECORYS, 2008; Schleich, 2009; Trianni et al., 2013)). Different aspects of energy efficiency in the iron and steel sector in Europe have been analyzed in several studies. Oda et al. (2012), for example, analyzed the specific energy consumption of different steel production routes in selected countries. The changes in specific energy consumption of the iron and steel sector with focus on the historical deployment of different steel production routes had been described e.g. by Arens et al. (2012), Price et al. (2002), Liu et al. (1996), Schleich (2007) and

¹ According to EEA the share of "Iron and Steel" on energy related greenhouse gas emissions accounts to 22% of total industrial emissions in the EU 27 (EEA, 2013). The final energy consumption of this sector equals 18% of the industrial energy consumption (Eurostat, 2012)

² In the Davignon Plan the Commission pursued an increasingly interventionist policy in order to address the deep steel crisis in Europe between 1975 and the late 1980s (Dudley and Richardson, 1997).

Worell et al. (2001). Dahlstrom & Ekins (2006) analyze the value chain of the UK iron and steel industry. A case study with information on the factors determining energy efficiency for a steel mill was carried out by Siitonen et al. (2010). In the studies of Hasanbeig et al. (2013), Hildalgo et al. (2005), Moya & Pardo (2013), Oda et al. (2007) and IEA (2012) information on cost of different steel production techniques are used for creating scenarios on the future of the energy demand of the iron and steel industry. Impacts of changes in the cost on the iron and steel demand and supply have been also analyzed by using top-down models. In these models usually aggregated production functions with elasticities are used for the assessment of energy reduction and fuel substitution options (see, e.g., Alexeeva-Talebi et al., 2012). Technological aspects are only taken into account in a very aggregated way (Schumacher and Sands, 2007).

Based on historical data on prices of energy carriers, on prices for the feedstock in the iron and steel sector, on political framework conditions and the demand for steel we analyze the impacts of these factors on the specific energy consumption as well as on the overall steel production without assuming perfect markets as it is assumed in forecast models and without a limitation of the analysis to technical aspects as it is done in most of the bottom-up studies. Germany, Italy, France, Spain and Great Britain as the five major steel production countries in the EU are selected as examples for working out the effects of differences in prices and impacts of changes in efficiencies.

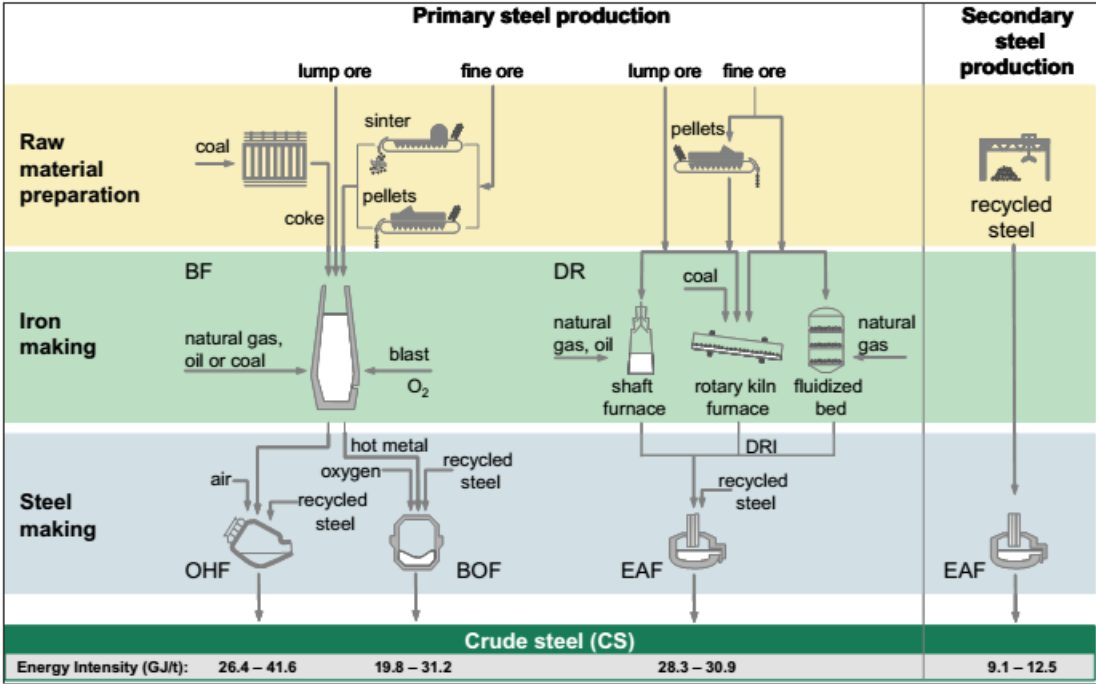
The paper is structured as follows: In Section 2, we provide some information on the iron and steel production. In Section 3, we describe the approach chosen for this study, the data used and the results. Section 4 puts the results into a broader context and draws conclusions.

2 Technologies, costs and efficiency

For the assessment of specific energy consumption in the iron and steel sector it is necessary to take a closer look on the techniques and production processes in use. An overview of the main production routes is presented in Figure 1.

In the recent years nearly 70% of the crude steel supplied worldwide has been produced by using the blast furnace/basic oxygen (BF/BOF) production route (World Steel Association, 2013). This route compresses the steps “raw material preparation”, “iron making” and “steel making”: Firstly, iron ore and coal as main feedstock have to be prepared by converting coal to coke and sintering and pelletizing the iron ore. In a next step, with the help of coke, the iron ore is converted to “hot metal” using a blast furnace. Afterward the hot metal is refined using a basic oxygen furnace.

Figure 1: Steel production route



Remarks: BF: Blast furnace, DR: Direct reduction, OHF: open hearth furnace, BOF: basic oxygen furnace, EAF: electric arc furnace
 Source: (World Steel Association, 2008)

About 29% of the crude steel is produced by using the Electric Arc Furnace (EAF) production route. Instead of iron ore and coke, scrap is used as main feedstock for this production route. In the electric arc furnace the scrap is converted to crude steel by using electricity as energy source. In principle the process can run by using pig iron provided by using direct reduction (DR) or smelting production techniques instead of scrap. In the “direct reduction” production process iron ore is reduced in solid state by using natural gas or coal as reducing agent. Coal is also used for the smelting reduction process. This technology compresses solid-state reduction of iron ore with gasified coal, and iron smelting (European Commission and Joint Research Centre, 2013). In Europe, the direct and the smelting production processes are currently not in use to a significant extent because of high cost involved. Therefore our analysis is focused on the BF-BOF and EAF production routes.

Regarding crude steel production, specific energy demand and CO₂ emissions vary significantly depending on which production route is selected.³ Taking into account the high energy demand which is needed for feedstock preparation, the energy demand of the BOF route is significantly higher than the one of the EAF route (see Figure 1, Table 1). For the calculation of CO₂ emissions, the CO₂ emission factor assumed for electricity is very important because of the low direct CO₂ emissions of the EAF route. The factor of CO₂ emissions for electricity is always lower than the one for coal and

³ See (IEA, 2008; Karbuz, 1998; Phylipsen et al., 1997; Siitonen et al., 2010) for information on the impacts of boundary definitions on specific energy consumption.

gas. The EAF-production route uses electricity as energy source and not coal like in the BOF production route. CO₂ emissions for the EAF route are lower than for the BOF route. The differences in CO₂ emissions between both production routes are bigger, if only direct CO₂ emissions are compared. An increase in the share of EAF on the overall crude steel production will result in a lower specific energy demand of the iron and steel sector and in a reduction in the specific CO₂ emissions. However, there are some factors which limit the potential for technique substitution. One aspect is the quality of the crude steel and another one is the availability of scrap.

Table 1: Example for Cost Structures of Steel Production Routes [\$/ton Steel]

	Unit	Unit cost [\$ /unit]	Basic Oxygen Furnace Route			Electric arc furnace Route				
			Factor	Fixed [\$]	Variable [\$]	Total [\$]	Factor	Fixed [\$]	Variable [\$]	Total [\$]
Iron ore	T	54	1.765		95.3	95.3				
Iron ore transport	T	24	1.765		42.4	42.4				
Coking coal	T	93	0.697		64.8	64.8				
Coking coal transp.	T	34	0.697		23.7	23.7				
Steel scrap	T	308	0.136		41.9	41.9	1.09		335.7	335.7
Scrap delivery	T	8.75	0.136		1.2	1.2	1.09		9.5	9.5
Oxygen	m ³	0.09	210		18.9	18.9	50		4.5	4.5
Ferrous alloys	T	1662	0.011		18.3	18.3	0.011		18.3	18.3
Fluxes	T	35	0.56		19.6	19.6	0.06		2.1	2.1
Electrodes	T	6500			0.0	0.0	0.003		19.5	19.5
Refractories	T	700	0.011		7.7	7.7	0.005		3.5	3.5
Other costs				5.0	15.0	20.0				
By-product credits					-31.0	-31.0				
Thermal energy, net	GJ	11.4	-2.4		-27.4	-27.4	0.43		4.9	4.9
Electricity	MWh	70	0.129	1.4	7.7	9.0	0.4		28.0	28.0
Labour	Man hr	30	0.5	3.8	11.3	15.0	0.4	5.5	6.5	12.0
Capital charges				34.0		34.0		9.0		9.0
Total				44.1	309.3	353.4				447.0

Source: (ECORYS, 2008)

As outlined above, for the BOF and EAF production routes different kinds of feedstock and different amounts of energy are necessary. Correspondingly, the cost structure of the production routes differs, too (see Table 1).

The development of the production mix used in the iron and steel sector, and therefore changes in the efficiency, depends not only on the specific cost factors of the selected production route but also on the cost structure of the competing technique.

Changes in costs, e.g. caused by lower specific energy use, can result in reduced overall costs. This may improve the competitive position of the company using the energy efficient technology.

3 Analysis

3.1 Overview

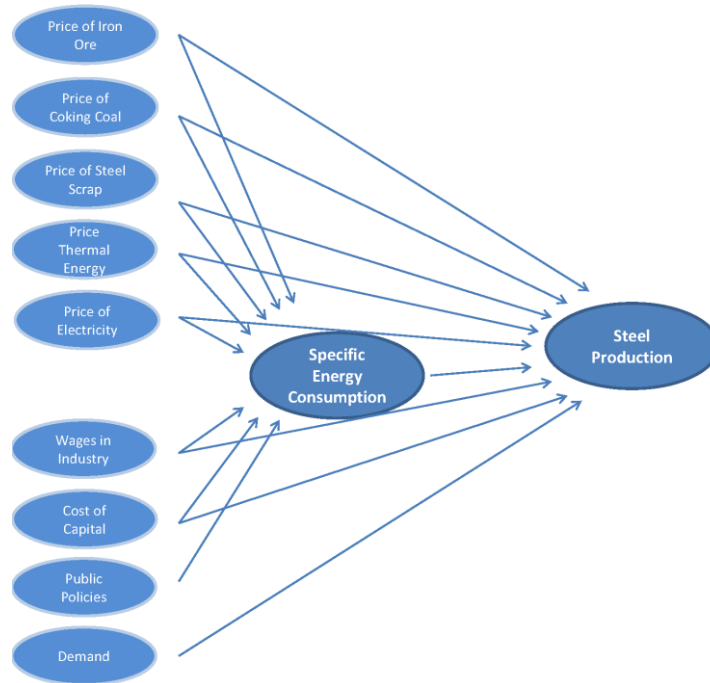
The above discussion has described that the EAF production route consumes significantly less energy than the BOF production route. Furthermore EAF and BOF steel making differ in the inputs needed for production.

In the following we analyze, on the one hand, how changes in the input prices lead to changes in specific energy consumption for steel. This relation is illustrated in Figure 2 by the directed arrows from input prices to the specific energy consumption of steel production. We focus on those inputs that significantly contribute to the total costs of steel production via the EAF or BOF routes as shown in Figure 1. Price changes that make the EAF production route relatively more attractive to the BOF route should lead to a decline in the specific energy consumption of steel making. While significant energy conservation is expected by a substitution from the BOF routine to the EAF routine, energy conservation improvements within each routine are also possible. Hence, an increase in input prices can also lead to reductions in specific energy consumption within each routine. Analyzing the relation between input prices and specific energy consumption thus allows for substitution between production routes and energy conservation improvements within single routines. Beyond input prices, public policies directed towards energy efficiency may also trigger a decline in specific energy consumption.

On the other hand, we analyze the impact of input prices on total steel production. While increases in specific input prices may lead to reductions in specific energy consumption, they may also have a direct effect on production as illustrated by the directed arrows from the input prices to total steel production in Figure 2. In general we would expect that price increases in one country relatively to those in other countries trigger a decline in production. Yet, the total effect of price increases in input factors is less obvious. In Figure 2 the total effect of price increases in input factors can be thought of as the sum of all directed arrows leaving the input prices and reaching total steel production either directly or indirectly via the specific energy consumption of steel. Price increases of input factors may encourage a substitution from the BOF to the EAF routine as well as improvements

within each production routine, leading to a decline in specific energy consumption as explained above. This decline in specific energy production may in turn foster total steel production. In general total steel production is also affected by overall economic demand.

Figure 2: Relation of Inputs to Specific Energy Consumption and Steel Production



3.2 Data and empirical specification

More generally we can think of steel production Q being a function of the price of steel, $P_i(D)$, which in turn depends on demand for steel, D , the prices of its input factors, P_k , and potentially other factors, Oth , as summarized in equation 1:

$$Q = b_0 + b_1P_i(D) + b_2P_k + b_3Oth \quad (1)$$

The prices of input factors, P_k , likely affect the specific energy consumption of steel production, SEC , as mentioned above. We can express this by $SEC(P_k)$, which leads to equation 2:

$$Q = b_0 + b_1P_i(D) + b_2^*P_k + c_1SEC(P_k) + b_3Oth \quad (2)$$

The difference between equation 1 and equation 2 is that in equation 1 b_2 shows the total effects of input prices on production, while in equation 2 b_2^* expresses the direct effects of input prices on production separately from the indirect effects that go via specific energy consumption.

For our empirical analyses we build on the relationships expressed graphically in Figure 2 and more formally in equation 1 and 2. In the following we shortly line out how these relationships translate to

the regression analyses in Section 3.3.2. The focus of the regression analyses lies explicitly on those factors that vary between countries or over time for explaining differences in steel production or its specific energy consumption.

The steel market is very global and competitive. Hence price differences between countries are low. If there are any, they likely reflect differences in transport costs or in import or export restrictions. Given that there is a single market for steel in the European Union there are no differences in import and export restrictions for steel between Germany, Italy, France, Spain and Great Britain. Yet, some differences in transport costs may exist. If the demand for steel varies between countries some price differences may thus emerge, which in turn may affect the production of steel. In our empirical analysis we account for the demand for steel by overall economic demand, namely $GDP_{i,t}$.⁴ Differences in demand over time, t , are accounted for via dummy variables for each year. Prices for input factors, $P_{k_{i,t}}$, may vary between countries and over time. Other factors may either be common to all countries and thereby captured by the dummy variables for each year, t , or specific to some countries, in which case they can be addressed by country fixed effects as discussed in Section 3.3.2 in more detail. The error term, $\varepsilon_{i,t}$, captures all remaining factors that may lead to random disturbances in steel production. Summing up, we estimate the following two specifications for explaining steel production, $Q_{i,t}$:

$$Q_{i,t} = \beta_0 + \beta_1 GDP_{i,t} + \beta_2 P_{k_{i,t}} + \beta_3 t + \varepsilon_{i,t} \quad (3)$$

$$Q_{i,t} = \beta_0 + \beta_1 GDP_{i,t} + \beta_2^* P_{k_{i,t}} + \gamma_1 SEC(P_k)_{i,t} + \beta_3 t + \varepsilon_{i,t} \quad (4),$$

Specification 3 corresponds to equation 1 and focuses on the total effects of the explanatory variables, while Specification 4 looks explicitly at the impact of the mediating variable specific energy consumption on total steel production and thereby corresponds to equation 2.

We are interested as well in the determinants of the specific energy consumption of steel production. On the one hand the specific energy consumption of steel is expected to depend on the price of input factors as already outlined above. On the other hand public policies, PP , might also affect the specific energy consumption, or energy efficiency of steel production.⁵ We therefore additionally estimate the following specification:

⁴ Controlling for overall economic demand by GDP may actually introduce some endogeneity to our regression framework because steel production is a component of overall GDP. Yet the share of steel production in overall GDP is very small, so that we consider the potential endogeneity problem as negligible.

⁵ If public policies have indeed an effect on energy efficiency and specific energy consumption turns out to be a significant predictor of total steel output, public policies should also be included specification 3. Otherwise we would have an omitted variable bias. Yet, if it turns out that public policies do not affect specific energy consumption, there is no need of including them in specification 3.

$$SEC_{i,t} = \delta_0 + \delta_1 P_{k_{i,t}} + \delta_2 PP_{i,t} + \beta_3 t + \varepsilon_{i,t} \quad (5)$$

Data

Table 2 shows the data we use for our analysis. Data on steel production originates from *Wirtschaftsvereinigung Stahl* (2012). Specific energy consumption has been calculated by dividing total steel production by its total energy consumption following the approach of the *Odyssee Database* (Enerdata/ADEME, 2012). The latter is retrieved from Eurostat (Eurostat, 2013)). GDP is measured in constant 2005 US Dollar and retrieved from the OECD iLibrary (OECD, 2013b). Gross fixed capital formation (GFCF) as percentage of GDP stems from the same database OECD (OECD, 2013c) and is derived by dividing GFCF through GDP.

Prices for electricity and gas in industry have been converted to constant 2005 US Dollars and are also retrieved from the OECD iLibrary (OECD, 2013a, d). Regarding electricity prices one should note that the prices are an average for industry as collected by the International Energy Agency (IEA). Electric-Arch Steel mills may actually face lower rates as they consume huge amounts of electric energy and thereby are offered better conditions by electricity providers. Therefore, we also used data by Eurostat, which offers more detail on prices for high volume electricity consumers. Given that there a lot of missing values for high volume energy consumption we had to impute data for many countries, relying on information of general electricity movements as well as on price differences between different consumption volumes. We run all regressions that are reported subsequently also with the imputed electricity prices. Given that we did not find any systematic differences we stucked with the electricity prices for industry as provided by the IEA.

Prices for iron ore, coking coal, and steel scrap, which have been converted to constant USD per metric ton, were calculated based on trade values and net weights retrieved from the *comtrade database* (United Nations, 2013a, b, c). Labor costs in manufacturing in constant USD per hour are from the United States Bureau of Labor Statistics (2011). In addition to the data shown in Table 2 public policies may also affect the energy consumed by steel production and thereby steel production itself. An overview of public policies regarding the steel sectors in Germany, Italy, Spain, France, and Great Britain is given in the following paragraphs.

Table 2: Summary Statistics

Variable	Variable Description	Mean	S.D.	Source ⁺
Steel Production	volume of steel production in kt	23804	10877	(Wirtschaftsvereinigung Stahl, 2012)
Spec. Energy Cons.	specific energy consumption of steel production in TOE/kt	0.32	0.06	(Eurostat, 2013; Wirtschaftsvereinigung Stahl, 2012)
GDP	gross domestic product in billion USD at constant 2005 prices	1679.20	499.13	(OECD, 2013b)
Price Iron Ore	price of iron ore in constant USD/t	42.73	18.51	(United Nations, 2013b)
Price Coking Coal	price of coking coal in constant USD/t	158.12	73.57	(United Nations, 2013a)
Price Steel Scrap	price of steel scrap in constant USD/t	310.47	228.22	(United Nations, 2013c)
Price Gas	price of gas in industry in constant USD per MWh	21.75	7.71	(OECD, 2013d)
Price Electricity	price of electricity in industry in constant USD per MWh	91.64	37.14	(OECD, 2013a)
Labor Cost	labor cost manufacturing in constant USD per hour	21.75	4.91	(United States Bureau of Labor Statistics, 2011)
GFCF/GDP	gross fixed capital formation in private sector as percentage of GDP	20.21	0.03	(OECD, 2013c)
Public Policies	See next section			

Public policies

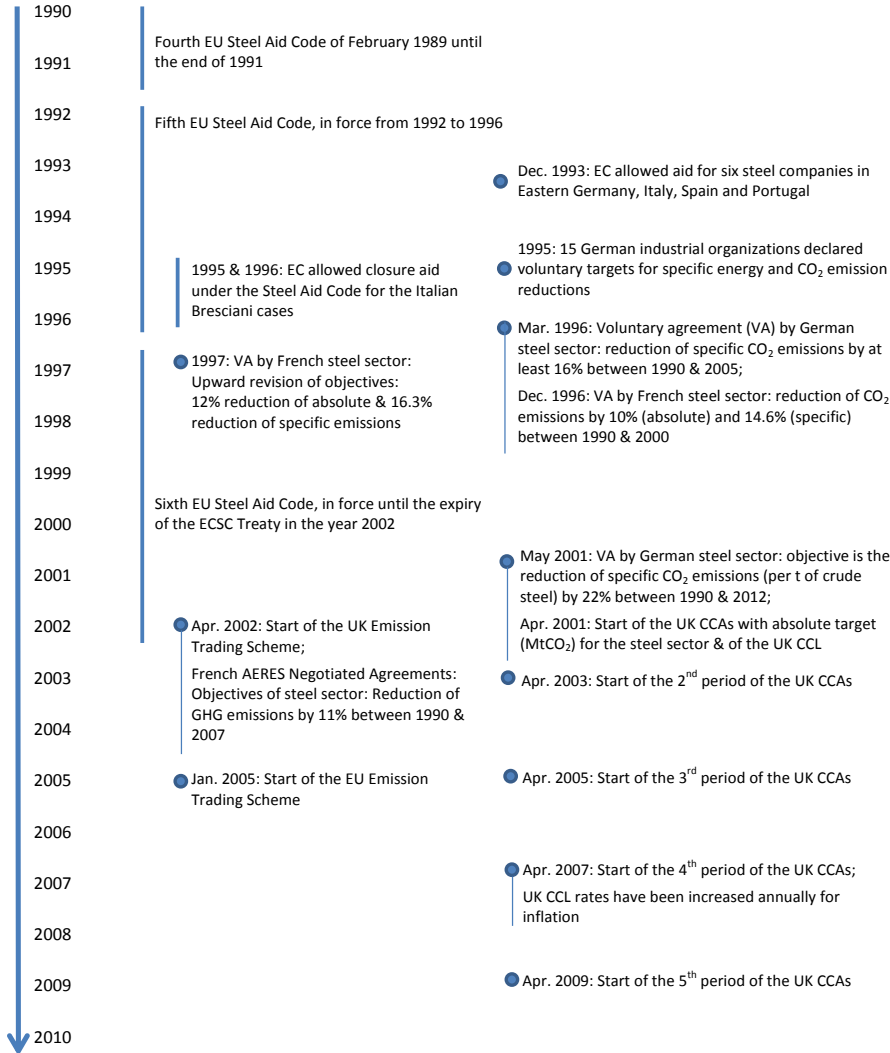
The steel sectors' efficiency efforts (both in terms of energy use and greenhouse gas emissions) may be directly influenced by public policies and voluntary agreements (see Figure 3). These public policies can largely be divided into the two groups of (granting) 'direct aid', and (implementing) 'emission trading'.

Direct aid in the considered time frame was regulated under the fourth (1989-1991), fifth (1992-1996) and sixth (1997-2002) EU Steel Aid Codes. State aid for the steel sector has mainly been granted for restructuring activities in order to address overcapacities in the sector. Also aid for research, development and environmental protection was allowed. With the expiration of the steel aid codes in 2002, the steel products have been integrated in the Common Market.

Emission trading was first introduced in the UK in 2002. In 2005 the EU emission trading scheme (ETS) followed.

In contrast to these public policies, the instrument of voluntary agreements did not affect the steel sector in all five considered countries. In different shapes, such agreements could only be found in France, Germany and the UK.

Figure 3: Overview of Mainly Relevant Historical Energy Efficiency Related Policies (1990-2010)



In Germany, the industry declared voluntary commitments with the expectation that the governmental regulator would – as a consequence of this – refrain from regulatory or fiscal instruments. Indeed, in response to the commitments from 2001, the German government confirmed that – given the successful implementation and joint development of the agreements – it will desist from introducing regulations (apart from those required by EU law) like the introduction of energy audits (RWI, 2011).⁶

The UK Climate Change Agreements (CCAs) brought about an 80% discount on the UK Climate Change Levy (CCL) for those companies/sectors signing an agreement. If these entities met their

⁶ Already in response to the 1996 commitments, the German government declared that it will prefer private sector initiatives to governmental regulations (RWI, 2011).

target laid down in the agreement, they continued to receive the discount for the next two years. All companies participating in the CCA scheme could participate also in the UK Emission Trading Scheme. In the phase of the EU ETS between 2005 and 2007, CCA firms could choose between joining the EU ETS and staying in the CCA. Joining the EU ETS became compulsory from the phase between 2008 and 2012. The CCAs continued for those sectors and activities not covered by the EU ETS (for a more comprehensive description of CCAs, CCL and UK ETS see, e.g. (Dijkstra and Rübhelke, 2013)).

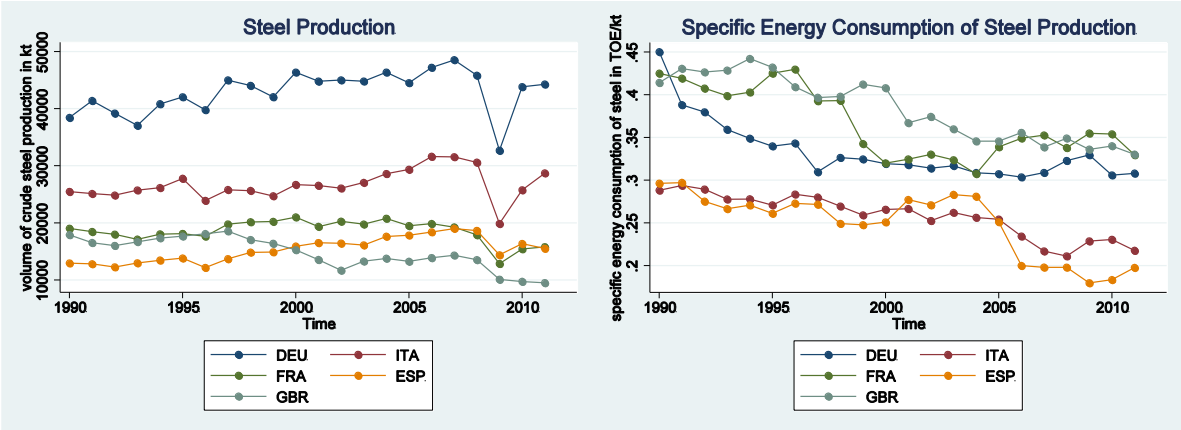
In France, the first set of voluntary agreements (1996-2002) was completely voluntary, while the second one (2002-2007 with commitment periods 2003-2004 and 2005-2007) involved penalties for breaching the agreement. With expiration of the second set of agreements in 2007 no such agreements were in force in France anymore.

3.3 Results

3.3.1 Graphical results

Figure 4 shows the development of total steel production and its specific energy consumption. We observe that steel production has increased in Germany, Italy and Spain over the last twenty years. The increase in Germany has been mostly in the 1990s while in Italy and Spain it was mostly in the 2000s. Steel production in France declined slightly and in Great Britain even to a stronger extent. The impact of the financial crisis can be seen clearly by the drop in production in 2009 in all countries.

Figure 4: Steel production and specific energy consumption



With view to the specific energy consumption of steelmaking at least two results emerge. First, Germany, France and Great Britain have rather high specific energy consumption, while Italy and Spain have rather low specific energy consumption. The latter two countries also have the highest shares of steel produced by the EAF route. Second, while we see a decline in specific energy consumption for Germany, France and Great Britain mainly in the 1990s and a stable development

from then onwards, the opposite is the case for Italy and Spain. In the 1990s their specific energy consumption only decreased slightly, while we observe a huge decrease in the 2000s. Correspondingly, we find that EAF steelmaking increased substantially in the latter two countries in the 2000s.

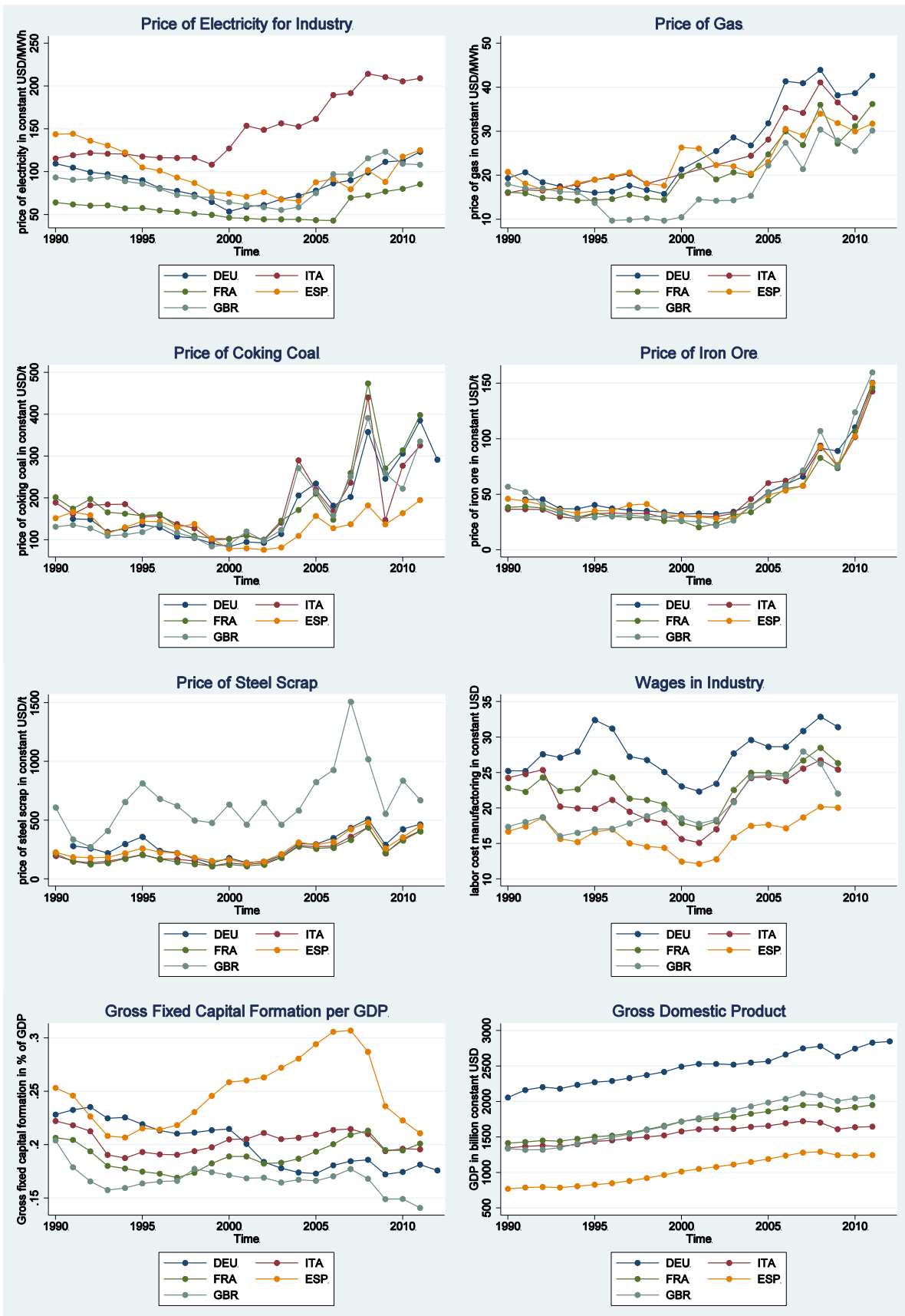
Comparing both graphs it seems that there is a negative relationship between total steel production and specific energy consumption, or in other words a positive relationship between total steel production and energy efficiency. Yet the corresponding correlation coefficient is negligibly small and also not statistically significant. We will return to this relationship when analyzing the data within a regression framework.

So far we did not account for the impact of any input factors on total steels production and its specific energy consumption. These factors could both influence production and energy consumption. Thus, when drawing any conclusions about the relationship between steel production and specific energy consumption, one should always take into account the impact that one or more of these input factors could have had.

Generally, for explaining differences in the developments of steel production and its specific energy consumption, one should focus on input factors that vary between countries. If input factors behave in the same way across different countries, i.e., there is no heterogeneity among them, they can hardly explain any divergent developments. However, those input factors that vary between countries can potentially explain some differences in steel production and specific energy consumption.

Prices for iron ore, steel scrap with the exemption of Great Britain, and to a lesser extend for coking coal hardly differ by country. Thus, these inputs are unlikely to explain the divergent movements of steel production and energy consumption.

Figure 5: Prices of inputs



Quite differently, prices for electricity and gas, wages, Gross Fixed Capital Formation (GFCF) as percentage of GDP, as well as GDP itself show more or less variance between countries. Regarding GDP, Great Britain and Spain grew strongest over the last twenty years. Yet we do not see any consistent relationship between steel production and GDP. In Great Britain steel production declined, while it increased in Spain. To some extent this may be related to growth in Spain being relatively more driven by the building sector and in the UK by the tertiary sector. With respect to GFCF/GDP, which is a proxy for overall investment, or more generally investment conditions, we see for Spain and Italy that GFCF/GDP and steel production moved in line in the 2000s. Furthermore, there is also some negative relationship for both countries between GFCF/GDP and specific energy consumption of steel making. Given that reductions of energy consumption, either via improvements of the existing steel making routes or by a switch from BOF to EAF steel making, are capital intensive, it is not surprising that a favorable investment climate goes hand in hand with energy conservation improvements.

Surprisingly we see that Italy and Spain, which face the highest prices for electricity, have also the lowest specific energy consumption in the steel production. Electricity is a major input to EAF steel making, which has low specific energy consumption. In comparison, BOF steel making, which is energy intensive, relies largely on coking coal as fuel input. Coking coal prices do not vary much across countries. We would have expected that due to high electricity prices BOF steel making is comparatively more attractive in Italy and Spain. Their specific energy consumption should be higher.

Going more into detail of the EAF route the puzzle can be resolved. While a switch from BOF to EAF steel making provides huge energy conservation, there are also considerable possibilities to reduce energy or more specifically electricity consumption within the EAF route (Environmental Protection Agency, 2012; European Commission and Joint Research Centre, 2013; Worrell et al., 2001). For example, scrap preheating can reduce electricity consumption by making use of the waste heat of the furnace to preheat the scrap and oxy-fuel burners can be used to substitute electricity with gas including flue gases. Thus, the EAF route may also be attractive with relatively high electricity prices.

All in all we see a reduction in specific energy consumption that goes along with an increase in input prices, mostly in the 2000s. Production stayed stable or increased slightly over the last twenty years. Surprisingly we see that countries with high electricity prices, i.e., Italy and Spain both have a very low specific energy consumption (due to an extensive application of energy efficient but electricity intensive EAF technologies) and could increase their total steel production quite significantly over the last 20 years.

3.3.2 Regression results

The graphical analysis above provides a first picture on the relationship between total steel production, its specific energy consumption and input prices. Comparing the relation between inputs and production as well as energy consumption gives first hints which relationships may matter. Yet the different input prices may also be correlated with each other. Ignoring this correlation can lead to spurious conclusions. In the following we account for the correlation between input prices by making use of a regression framework.

The estimator we apply is a generalized least squares (GLS) estimator for panel data that allows for both, correlation of error terms between countries, and country specific serial correlation as outlined below. It is implemented, for example, in STATA by the `xtgls` command (Stata, 2009). For robustness we also run all regressions with the panel corrected standard errors (PCSE) approach suggested by Beck and Katz (1995). As results do not differ systematically we only report the GLS estimates.

Countries experience common shocks over time like the global financial crisis that started in 2008. We account for the impact of common shocks by introducing dummy variables for each specific year, which take over year specific effects.

Even after controlling for common shocks it is likely that neighboring countries like Germany and France, which trade a lot with each other, also move more in line regarding all kinds of economic developments than countries like Great Britain and Italy, which are further away from each other and also trade less with each other. We account for this relationship by allowing the error terms of countries to be correlated with each other. For estimating this cross-country correlation we need a balanced panel and for valid results more observation over time than countries (c.f. (Beck and Katz, 1995)). Our data fulfills these requirements as we analyze the five biggest steel producing countries in the EU over the last twenty years.

Observations are likely to be correlated over time. We keep all input prices and GDP in real terms in order to avoid any common correlation introduced by inflation. Furthermore, our error terms account for country specific serial correlation.

We run all our regression models once with country fixed effects (FEs) and once without. In general country FEs cancel out unobserved heterogeneity and thus provide more consistent estimates. Regarding steel production and its specific energy consumption, the story may be more complicated. Steel production is very capital intensive and the way how steel is produced is very dependent on the production facilities already in place. These production facilities are in turn a likely consequence of general economic and steel specific circumstances when they were built. Hence, estimations including country FEs will cancel out historic dependencies and thereby provide estimates of, so to

say, short-run effects. Estimations not including FEs bear the risk that unobserved heterogeneity leads to an omitted variables bias and thus spurious results. Yet, our analysis is grounded in the cost structures of steel production routes as summarized in Table 1. Furthermore, we only analyze countries within the European Union. These countries are relatively homogenous compared to the rest of the world and face common trade rules. Thus, we hardly expect any unobserved heterogeneity. The results of the estimations without FEs may thus be interpreted as so to say long-run effects as they do not cancel out historic dependencies.⁷

3.3.2.1 Steel production

Table 3 shows the regression results for steel production. Regressions 1 and 3 correspond to Specification 4 in Section 3.2 and include the specific energy consumption of steel production as explanatory variable. The coefficients for the input prices may therefore be interpreted as the direct effects (DE) of those variables that are not already accounted for by their impact on the specific energy consumption of steel making. Regressions 2 and 4 correspond to Specification 3 in Section 3.2 and do not include the specific energy consumption separately. These coefficients can be thought of as the total effects (TE) of input prices on steel production.

A decrease in the specific energy consumption of steel production, or alternatively an increase in the energy efficiency of steel production corresponds to a statistically and economically significant increase in steel production. This relation holds both for Specification 1 without country FEs and for Specification 3 with country FEs. In the first case without country FEs, a one percent increase in energy efficiency corresponds to a 0.534 increase in steel production, while with country FEs the same increase in energy efficiency corresponds only to a 0.312 increase in steel production. These results match with the above discussion that FEs specifications relate more to short-run effects while the specifications without more to long-run effects.

GDP as a proxy for demand has positive coefficients throughout as expected. It is stronger and statistically significant when not accounting for FEs. GDP then takes account of the overall differences in steel production. Note as well that the coefficients hardly differ depending on whether one accounts for specific energy consumption or not. This can be interpreted as evidence that GDP identifies well the steel demand but that GDP has no impact on the steel sector's specific energy consumption.

⁷ We also ran dynamic panel data regression models that account for path dependencies with the help of a lagged dependent variable. These models usually require a large N small T panel dimension for robust results and thus do not really fit our data. Tests for over-identification, serial correlation, and upper and lower bounds of the lagged dependent variable yet did not reject the validity of the results. In general coefficient estimates lay between the regressions including and excluding country fixed effects.

Table 3: Steel Production

	(1)	(2)	(3)	(4)
	GLS, DE	GLS, TE	GLS, DE	GLS, TE
Spec. Energy Cons.	-0.534*** (-7.50)		-0.312*** (-3.85)	
GDP	1.297*** (12.71)	1.219*** (11.85)	0.206 (0.80)	0.232 (0.80)
Price Iron Ore	0.141* (2.10)	0.188* (2.11)	0.113* (2.12)	0.0911 (1.47)
Price Coking Coal	-0.125*** (-3.41)	-0.140** (-2.93)	-0.0436 (-1.38)	-0.0258 (-0.73)
Price Steel Scrap	-0.0833* (-2.07)	-0.106* (-2.37)	-0.0110 (-0.31)	-0.0276 (-0.69)
Price Gas	-0.0594 (-0.98)	0.0234 (0.32)	-0.144* (-2.40)	-0.130* (-2.00)
Price Electricity	0.198*** (6.30)	0.265*** (6.23)	-0.0624 (-1.44)	-0.0861 (-1.74)
Labor Cost	-0.174 (-1.39)	-0.171 (-1.12)	-0.458*** (-4.48)	-0.446*** (-4.10)
GFCF/GDP	0.215* (2.01)	0.503*** (3.89)	-0.0773 (-0.71)	-0.000573 (-0.00)
Italy			-0.533*** (-4.17)	-0.438** (-3.22)
France			-0.856*** (-7.67)	-0.896*** (-7.08)
Spain			-1.166*** (-4.49)	-1.061*** (-3.73)
Great Britain			-1.131*** (-9.72)	-1.134*** (-8.86)
Year Dummies	included	included	included	included
<i>N</i>	95	95	95	95
chi2	4675.1	2102.4	34832.2	22380.2

t statistics for standard errors with correlation between countries and country-specific ARI autocorrelation structure in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; all variables in natural logarithm except dummies for voluntary agreements, countries, and years; prices in constant 2005 USD; constants not shown

The price of iron ore, a major input to BOF steel making, is economically and statistically positively related with steel production throughout. Depending on the specification, a one percent increase in the price of iron ore corresponds to a 0.09 to 0.19 percent increase in total steel production. Correspondingly, the price of steel scrap, a major input to EAF steel making, is negatively related to total steel production. Statistically it is only significant in the specifications without country FEs, which correspond more to the long-run effects. These two findings suggest that steel production in Europe relates positively to a cost structure that is beneficial for steel production via the more energy efficient EAF production route.

The price of coking coal, a main input to BOF steel making, is associated negatively with steel production. Yet, it is only statistically significant in the specifications without country FEs. Higher prices for coking coal may thus lead to a decline in BOF steel making over time.

The price of gas, which was thought of as a proxy for the heat that is generated by the BOF route is negatively related with total steel production when controlling for country FEs. Higher gas prices should make the BOF route relatively more attractive, either through higher revenues from sales of excess heat or via higher costs for those EAF steel routes that also make use of oxy-fuel burners. Hence, it seems that a change in gas prices that is favorable to the BOF routine affects total steel production in the short-run negatively.

Higher electricity prices are associated positively with total steel production in the specifications without country FEs. As already mentioned in the graphical analysis, this is quite surprising as we see that Italy and Spain, which face the highest prices for electricity, have also the highest share of steel making by the EAF route, which uses electricity as a major input. We would rather have expected lower production with higher energy prices. Yet, as already explained, there are also multiple ways for electricity conservation in the EAF route [cf. Worrell, Martin, and Price, 1999, Environmental Protection Agency, 2012, Remus et al., 2013]. In the specifications with FEs, that correspond more to the short-run effects, we do not observe any statistically significant relation between electricity prices and steel production.

Labor costs, a major input to both production routes are negatively related to steel production. The coefficients are statistically significant for the specifications with country FEs. This may be interpreted in the way that in the short-run a one percent increase in labor costs leads to a 0.45 decrease in total steel production.

GFCF/GDP, which is a proxy for investment conditions, is statistically and economically positively related to steel production in the longer term in the specifications without FEs. This result is as expected given that steel production in general is capital intensive and also a switch from BOF steel making to EAF steel making requires significant capital.

In general one may also account for public policies that could influence steel production via their impact on specific energy consumption. We do not report them in Table 3 as they did not have any economic nor statistical significant impact. Yet, in the following analysis of specific energy consumption we consider the impact of public policies in more detail.

3.3.2.2 Specific energy consumption

Table 3 showed that the specific energy consumption of steel making is negatively related to total steel production, or in other words, the energy efficiency of steel making is positively related to steel making. In addition, Table 3 also showed the direct and total effects of input prices on total steel production. We now go into more detail and focus on the determinants of the specific energy

consumption of steel making. Table 4 shows the respective regressions that correspond to Specification 5 in Section 3.2.

We do not see any significant relation between prices of iron ore or gas and specific energy consumption. Also labor costs are not significantly related to specific energy consumption.

Coking coal prices are statistically and economically negatively related to the specific energy consumption of steel making. A one percent increase in coking coal prices corresponds to 0.12 to 0.14 percent decrease in specific energy consumption. This result corresponds to a decrease in BOF steel making relative to EAF steel making. Vice versa steel scrap prices are statistically and economically positively related to specific energy consumption. Increases in steel scrap prices make the energy efficient EAF route compared to the BOF route less attractive.

Table 4: Specific Energy Consumption of Steel Production

	(5)	(6)
	GLS	GLS
Price Iron Ore	0.0913 (1.53)	0.0324 (0.59)
Price Coking Coal	-0.139*** (-4.46)	-0.117*** (-4.34)
Price Steel Scrap	0.0919*** (3.94)	0.0686* (2.08)
Price Gas	-0.0944 (-1.95)	-0.0460 (-1.03)
Price Electricity	-0.141*** (-3.38)	0.0774 (1.73)
Labor Cost	-0.0525 (-0.63)	-0.00754 (-0.11)
GFCF/GDP	-0.320* (-2.55)	-0.204 (-1.35)
Vol. Agreement	0.0172 (0.65)	0.00702 (0.32)
Italy		-0.273*** (-4.25)
France		0.131* (2.06)
Spain		-0.312** (-3.02)
Great Britain		0.0145 (0.21)
Year Dummies	included	included
<i>N</i>	95	95
χ^2	579.2	3960.1

t statistics for standard errors with correlation between countries and country-specific AR1 autocorrelation structure in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; all variables in natural logarithm except dummies for voluntary agreements, countries, and years; prices in constant 2005 USD; constants not shown

The price of electricity is negatively related to specific energy consumption in Specification 5, which does not account for country FEs, and might be interpreted more as the long run effects. As already explained this is consistent with higher electricity prices triggering electricity conservation within the EAF route. With country FEs (Specification 6), which may be interpreted as the short-run effects we do not observe any statistically significant effect of electricity prices. This seems plausible as improvements in electricity conservation take time and in the short-run we would rather expect a positive relation between electricity prices and specific energy consumption as the more energy intensive BOF route becomes more attractive.

GFCF over GDP, the proxy for investment conditions, is negatively related to specific energy consumption. In Specification 5, i.e., without country FEs, it is also statistically significant. This result makes sense as investments in energy conservation are capital intensive.

In addition to input prices we also looked at the impact of industry's voluntary agreements to cut carbon emissions in the steel sector as shown in Figure 3. We simply coded a dummy variable that takes the value of 1 if a voluntary agreement was in place and zero if it was not. Table 4 shows that these voluntary agreements, which are or have been in place in Germany, Great Britain, and France, had no impact on the specific energy consumption of steel making. This finding supports the apprehensions that signers of voluntary agreements mainly agree on what they would have done anyway.

Regarding specific energy consumption it is also worthwhile to have a closer look at the individual country FEs. We note that both Italy and Spain have a statistically significant negative coefficient for their country fixed effects. In the graphical analysis it has already been shown that both countries also have the lowest specific energy consumption of steel making. The negative fixed effects thus mirror the graphical results. If we believe that our explanatory variables capture the cost structure of steel production sufficiently well, then these fixed effects are just a result of historic input prices, which in this case favored a less energy intensive steel production in Italy and Spain. It follows that the coefficients for the input prices and the other explanatory variables in the regression with FEs should then also be closer towards zero as they correspond to the effects of year to year changes in input prices. The regressions without country FEs, in contrast, take the difference between the levels of input prices, which developed over longer time periods, into account and thus show coefficients which are larger in absolute size.

Summing up, we find substantial evidence that higher energy prices are related to lower specific energy consumption of steel making. Lower specific energy consumption is in turn related to a higher total production of steel. Altogether the relation between input prices and total steel production is

economically and statistically not very strong. In the short-run, wages have the biggest impact on steel production, while over longer time periods GDP and the investment climate have the strongest relation with steel production.

Our results provide some first evidence on the determinants of the relation between steel production, its energy consumption, and input prices. Ideally one would like to analyze more countries, equally homogenous as the considered EU countries, over longer time periods. Access to micro-data, i.e., plant specific data would surely also reveal new and more robust insights. Nevertheless, we think our rather simple graphical and statistical insights have opened the window for more studies on the economics and environmental viability of steel making.

4 Conclusions

The recent EU action plan for the European steel industry observes the need to stimulate growth in the EU steel sector, cut costs and increase innovative, sustainable steel production. Our paper sheds light on the links between these objectives, i.e. steel production growth, production cost cuts and (innovative) sustainable steel production. In particular we considered the role that input prices (e.g. energy prices) and policies (e.g. voluntary industrial agreements) may play in attaining an environmentally more sustainable, i.e. energy efficient, steel production, and how this - in turn - affect total steel production output.

As we found out and as economic intuition suggests, higher energy prices tend to raise energy efficiency (or tend to reduce specific energy consumption) in the steel sector. This tie between energy-price/-efficiency is due to economic agents' reaction to the price signal: they raise their efforts to diminish the adverse price-effect on their profits by lowering the use of the now more costly input.

However, there are different forms of energy inputs (e.g. electricity, coking coal, gas) in the steel sector and divergent paths (e.g. change of production routes or improvement of efficiency within one route) to attain lower specific energy consumption. The consequences of individual responses to energy price changes are far from being obvious. If electricity prices rise, for example, then a natural option to escape a major adverse impact on profits would be to substitute EAF by BOF steel making. However, as the BOF route is associated with higher specific energy consumption, this tends to worsen the steel sector's performance regarding energy efficiency and to contradict our result concerning the energy-price/-efficiency tie. Yet, as the examples of Italy and Spain showed, this is not necessarily the case as steel producers may react to an increase in electricity prices by reducing electricity consumption within the EAF route. Because lower specific energy consumption is related with a higher total steel production, energy price increases might cause a kind of rebound-effect

bringing about an increase in total production as a consequence of induced energy efficiency improvements. Altogether the negative relation between input prices and total steel production is not very strong. In the short-run, wages of employees in the steel sector tend to have the biggest influence on total steel production. In the long-run, GDP and investment climate exert the biggest influence.

These findings may help to guide public policies aiming (like the 2013 action plan for the European steel industry) at a more environmentally sustainable steel industry and/or stimulating production in this industry. Yet, there is still need for further research as our study only provided some first evidence on the determinants of the relationship between steel production, specific energy consumption and input prices. Future research should, e.g. also look at longer time periods and a larger number of countries, in order to investigate how reliable our results are also in different research frameworks.

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