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Sectoral Targets as a Means to Reduce Global Carbon Emissions.

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Sectoral Targets as a Means to Reduce Global Carbon Emissions

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Zusammenfassung

Sektorale Ziele werden als eine Möglichkeit diskutiert, das Risiko von Wettbewerbsverzerrungen und Carbon Leakage infolge von asymmetrischen Klimapolitiken oder klimapolitischen Zielen zu mindern (vgl. Baron et al. 2008, 2009; Fujiwara 2010, Center for Clean Air Policy 2010). Asymmetrien können in Bezug auf die betroffenen Länder oder Regionen auftreten sowie in Bezug auf die Stringenz der Klimaziele oder der wirtschaftlichen Auswirkungen von Zielen. Sektorale Ziele können als multi-sektorale Emissionshandelssysteme zwischen Ländern oder Regionen implementiert werden oder als transnationale Ansätze für energieintensive Sektoren wie z.B. dem Zement-, Stahl- oder Stromsektor oder im Bereich der Mobilität. Bisherige Untersuchungen zu sektoralen Ansätzen fokussieren sich zumeist auf qualitative und quantitative Partialanalysen einzelner Sektoren.

In der vorliegenden Studie werden die Effekte sektoraler Ziele in der internationalen Klimapolitik in einem makroökonomischen Rahmen untersucht. Im Fokus der Untersuchung steht die Interaktion der Ziele mit dem bestehenden EU Emissionshandelssystem und die Auswirkungen auf Minderungen möglicher Wettbewerbsverzerrungen. Sektorale Ziele werden für den Stahlsektor implementiert, der sich wegen seiner hohen CO_2-Intensität (3-5% der globalen Emissionen) und Handelsintensität (ca. 20% der Stahlproduktion wird international gehandelt) besonders eignet. Stahl kann im Wesentlichen auf zwei Arten produziert werden: die herkömmliche Sauerstoffstahlerzeugung auf Basis von Roheisen im Hochofen ist die CO_2-intensivere Produktionsart, die durch Kohle- und Kokseinsatz zu hohen direkten Emissionen führt. Die emissionsärmere Lichtbogentechnologie verwertet überwiegend Recyclingstahl und ist durch die Schmelzprozesse stromintensiv. Der Anteil der Produktionstechnologien des Rohstahls variiert stark zwischen Ländern/Regionen und hat einen wesentlichen Einfluss auf die Gesamtemissionsintensität der Stahlerzeugung in einem Land oder einer Region.

Während ingenieurwissenschaftliche Modelle mit ihrem Technologiefokus in der Regel zwischen verschiedenen Produktionsprozessen unterscheiden, ist dies typischerweise nicht der Fall für makroökonometrische Modell oder allgemeine Gleichgewichtsmodelle. Unsere Analysen zeigen jedoch, dass eine Unterscheidung von Technologieprozessen in makroökonomischen Modellen wichtige zusätzliche Erkenntnisse über ökonomische Auswirkungen und daher wesentliche politikrelevante Informationen bieten.

Summary

Sectoral approaches have been proposed as a means to address competitiveness and leakage concerns arising from asymmetric climate policy, where emission targets across countries and regions differ in terms of their environmental stringency or economic effects (e.g. Baron et al. 2008, 2009; Fujiwara 2010, Center for Clean Air Policy 2010). Such approaches may involve linking of multi-sector emissions trading systems (ETS) across countries and regions or transnational approaches for individual energy-intensive sectors, as proposed for the cement, steel or electricity sectors, or land transportation. Previous research of sectoral approaches mainly involves qualitative approaches or quantitative analyses for individual sectors based on partial equilibrium models.

This paper explores the effects of sectoral targets in international climate policy in a macroeconomic framework, their interaction with the EU emissions Trading System (EU ETS), and to which extent sectoral targets can address the concerns of competitiveness. We assume that a global binding agreement exists between the steel sector and governments. The steel sector seems particularly suited for a sectoral targets approach because it is relatively CO_2-intensive (3-5% of global CO_2-emissions) and also trade intensive (approximately 20% of the value of steel output is traded). Steel may be produced using two different technologies: a basic oxygen furnace (BOF) which produces steel from virgin raw materials or an electric arc furnace (EAF) which produces steel from recycled metal products. The percentage of steel produced by each process varies significantly across regions. BOF production is mainly associated with direct CO_2 emissions, while EAF causes primarily indirect emissions via electricity use. While most engineering-economic bottom-up models distinguish between different production technologies, this is typically not the case for econometrically estimated (macro)economic models or computable general equilibrium (CGE) models. Our findings illustrate that differentiating industrial technologies in a CGE framework allows to gain additional insights into major economic effects and thus provides policy relevant information.

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1 Introduction

Negotiating an international climate change agreement to replace the Kyoto Protocol has proven to be difficult. At recent United Nations Climate Change Conferences (UNFCCC) countries have agreed to limit the increase in the global surface temperature to 2°C and adopted emission pledges made by industrialized as well as major developing countries (Copenhagen, COP 15; Cancun, COP 16), and to commit to a legally binding agreement on climate change no later than at 2015 at COP 21 in Paris in that would take effect in 2020 (Durban, COP17). In particular, the challenge remains of how to integrate developing countries into a future framework. Developing countries have been reluctant to commit to limiting their future emissions, which they fear will slow their economic development. Conversely, some industrialized countries are reluctant to unilaterally commit to emission reductions unless other countries they compete with in international markets face similar emission restrictions.

On the other hand, because the top-down approach of the UNFCCC has not led to an international agreement on greenhouse gas emissions reduction targets or the legal form of any future agreement, alternative means to achieve emission reductions through other international group/forums with a more limited member-ship, such as the G20, the Major Economies Forum, or multilateral agreements at the sector level, are being considered. Such a bottom-up approach includes, for example no-lose targets (e.g., Philibert, 2000, Philibert, 2001, Bodansky 2003, Duscha and Schleich 2013) or sectoral approaches. The latter include the linking of multi-sector emissions trading systems (ETS) across countries and regions (e.g. Anger 2008; Jaffe et al. 2009; Flachsland et al. 2009; Tuerk et al. 2009) or sectoral targets, i.e. the joint binding agreements between sectors and governments of countries. Sectoral approaches are often perceived as a vehicle to entice major developing countries to participate in international climate agreements (e.g. Baron et al. 2008, 2009; Fujiwara 2010a, b, The Center for Clean Air Policy 2010, Sawa 2010). This may evolve within a portfolio of treaties (Barrett 2010) or within a staged approach over time (den Elzen et al. 2008). Sectoral targets could allow for efficiency gains while at the same time addressing the concerns of competitiveness and carbon leakage of industrialized countries. Sectoral targets have mainly been considered for energy-intensive sectors, such as the cement, steel or electricity sectors, and for land transportation (WBCSD 2009; Binsted 2010; Wooders 2010; Meunier and Ponssard 2012; Voigt et al. 2011, Hamdi-Cherif et al. 2011, Gavard et al. 2011).

Previous research of sectoral targets mainly involves qualitative approaches (e.g. Fujiwara 2010a,b; Baron et al. 2008, 2009) or quantitative analyses for individual sectors based on partial equilibrium models (e.g. Meunier and Ponssard 2012). In this paper, we explore the role of sector emission targets in future inter-national climate agreements in a macroeconomic framework, their interaction with the EU emissions Trading System (EU ETS), and to which extent sector targets may address competitiveness concerns for the steel sector. The steel sector seems particularly suited for a sectoral targets approach for two reasons. First, steel production is relatively CO2-intensive, accounting for about 3-5% of the global CO2 emissions. Second, the steel industry is trade intensive with approximately 20% of the value of steel output traded internationally (GTAP v.7 database).

Steel may be produced using two different technologies: a basic oxygen furnace (BOF) which produces steel from virgin raw materials or an electric arc furnace (EAF) which produces steel from recycled metal products. Because these two production process use different technologies, the percentage of steel produced by each process varies significantly across regions[1], and that BOF production is mainly associated with direct CO_2 emissions, while EAF causes primarily indirect CO_2 emissions via electricity use.

While some engineering-economic bottom-up models distinguish between different steel production technologies, this is typically not the case for econometrically estimated (macro)economic models or computable

[1] For example, in 2012 the share of EAF in total crude steel production was over 60% for some major steel producers like the US, Mexico, India, Italy, and Spain, but less than 30% in the UK, Russia, the Ukraine, Japan, and Australia. In China, the world's largest steel producer, EAF accounts only for about 10% of total crude steel production (World Steel, Statistical Yearbook 2013)

general equilibrium models. Exceptions include Lutz et al. (2005) for macroeconometric models, and Schumacher and Sands (2007) for CGE models. Since the regional scope of these models is limited to one country (Germany), they would not be able to adequately capture leakage and competitiveness effects.

To explore the implications of sectoral targets for the steel sector, we first modify an existing dynamic computable general equilibrium model to more adequately reflect steel production technologies. The model is then applied to investigate four different policy scenarios which differ by the number of sectors within and across countries facing emission targets, and to which extent trading of emission certificates is allowed between the sectoral targets sector (steel) and sectors subject to emissions trading.

The remainder of the paper is organized as follows. Section 2 presents the main features of the model. Section 3 describes how the steel sector is modelled. Section 4 provides the specific emission targets in each scenario and presents the model results. The final section discusses the main findings and concludes.

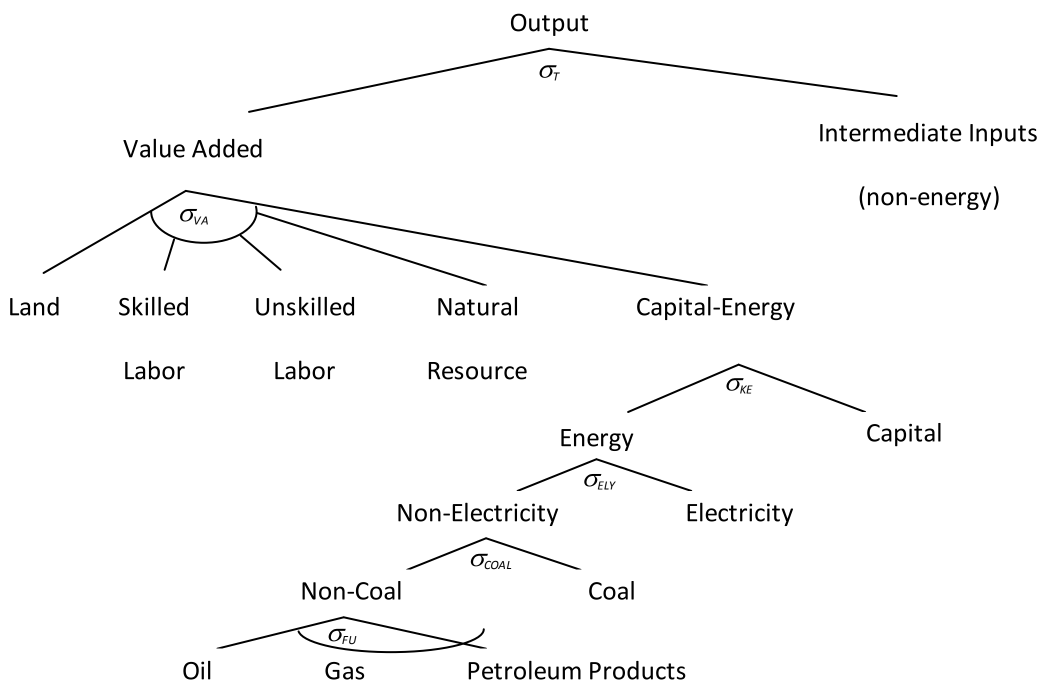
2 Modelling

2.1 Empirical Model

The analyses rely on a multi-country, multi-sector, recursive dynamic computable general equilibrium (CGE) model (DYE-CLIP), developed by Peterson et al. (2011), DYE-CLIP is based on the GDyn (Ianchovichina and McDougall, 2001) and GTAP-E models (Burniaux and Truong, 2002; Nijkamp et al., 2005), and utilizes the GTAP 7 database (2004 base year). Accordingly, households and firms are assumed to act perfectly rational but myopic. That is, they maximize utility or profits given the information available in a particular period. Relative factor prices drive companies' input portfolio and output prices drive demand and supply. Factor prices and output prices adjust instantaneously so that all markets clear in all time periods. Emission targets are achieved via taxes on direct CO_2 emissions. DYE-CLIP also includes domestic trade and transport margins.[2]

The use of energy commodities (coal, oil, gas, refined petroleum products, and electricity) as intermediate inputs is governed by a nested Constant Elasticity of Substitution (CES) production function as specified in the GTAP-E model (Burniaux and Truong, 2002). This production structure is illustrated in Figure 1. Firms cannot substitute among non-energy intermediate inputs or between non-energy intermediates and a primary factor composite. The primary factor composite is made up of land, skilled labor, unskilled labor, natural resources, and a capital-energy composite with a constant elasticity of substitution between them. Within the capital-energy composite, firms may substitute between an energy composite and capital. There are also three inter-fuel substitution possibilities: (a) electricity and the non-electricity composite; (b) coal and the non-coal composite; and (c) between oil, gas, and petroleum products. As pointed out by Burniaux and Truong (2002), this specification allows for substitution between fuels and allows capital and energy to be either substitutes or complements, depending on the chosen values of the elasticities of substitution.

Figure 1: Structure of productionn



[2] Peterson and Lee (2009) find that models that do not include domestic trade and transport margins can underestimate the level of a carbon tax needed to achieve a specific abatement target by 10-15%.

A key model parameter is the elasticity of substitution between capital and the energy composite, which we set equal to 1.0. [3] At this level, capital and energy are substitutes in all industries and regions in the model. In addition, because the model is solved in increments of four years, a unitary elasticity of substitution implies only modest substitution possibilities on an annual basis.

The direct consumption of energy commodities, mainly refined petroleum products (e.g., gasoline) and natural gas, by households is determined by their utility functions. Similar to the GTAP-E model, both a private and government household is identified. However, very small quantities of energy commodities are purchased directly by the government household in all regions in the GTAP 7 database. The demand for energy commodities by the private household is governed by a Constant Difference Elasticity of substitution (CDE) utility function, whose parameter values are set to the base values in the GTAP 7 database. The CDE function used does not nest energy commodities separately from non-energy commodities. The uncompensated own-price elasticities for energy commodities are inelastic, with the most inelastic responses in non-Annex I countries. The income elasticities for energy commodities are approximately unitary for most regions, except for elastic income responses in some non-Annex I countries.

A unique feature of the DYE-CLIP model is that it allows the supply of coal, oil, and gas to change as the prices for those commodities change. In the GTAP-E model, the supply of coal, oil, and gas is governed by the amount of a "natural resource" primary factor, which is specific to these sectors and whose supply is generally assumed to be fixed. In the DYE-CLIP model, three new sector-specific primary factors are created for the coal, oil, and gas sectors. The initial value of these primary factors are set equal to use of the natural resource primary factor by these sectors in the GTAP database. A constant elasticity supply function is used for each sector-specific primary factor, with an assumed supply elasticity of 0.25.

The model consists of 32 country/regions and has 18 sectors, including the sectors subject to emissions trading, i.e. electricity, refined petroleum and coal, chemicals, rubber and plastics products, other mineral products, paper products, and non-ferrous metals To allow for a more realistic modelling of steel production, the GTAP sector ferrous metals (i_s) is disaggregated into BOF steel and EAF steel industries[4].

2.2 The steel sector

2.2.1 Major steel production processes

The two most important processes for steel production rely on basic oxygen furnaces (BOF) or electric arc furnaces (EAF). The oxygen steel process involves producing primary materials following the route sintering plant (ore concentration) / coking plant - blast furnace (iron making) - converter (steel production). The electric arc furnace process involves producing secondary materials primarily in electric arc furnaces (to a lesser extent in induction furnaces) based on smelted down scrap. From an energy perspective, EAF steel is more attractive since it requires less than half the primary energy use of the BOF steel. The main energy input in the EAF process is electricity as opposed to coal and coke for the BOF process. Hence, CO_2-intensity of the two processes differs significantly between 0.4 mt of CO_2 per mt of crude EAF steel (excluding the indirect CO_2 emissions from electricity production) compared with 1.7-1.8 mt of CO_2 per mt of crude BOF steel (IEA, 2012). Taking into account indirect CO_2 emissions as well, the CO_2 emissions related to steel industry in a particular country not only depend on technological efficiency and the share of particular steel production processes, but also on the CO_2-intensity of the power sector. The higher the share of nuclear and renewable energy sources in electricity generation, the lower the CO_2 emissions associated with the production of EAF steel, ceteris paribus.

[3] There is an extensive literature on whether capital and energy are substitutes or complements, and what the correct parameter value is. Findings by Kemfert (1998) and van der Werf (2008), for example, suggest that energy and capital are substitutes.

[4] A technical description of the disaggregation of the ferrous metals sector is provided in the Appendix.

While there are also other steel production processes, involving for example, direct reduction processes, BOF and EAF steel currently account for 99% of global crude steel production (World Steel 2013). The shares of BOF and EAF steel differ significantly across countries and regions (see Table 8 in the Appendix). Besides the availability of primary inputs such as iron ore, coke or scrap and the demand for crude steel, also the prices and availability of electricity and scrap determine the amount and type of steel being produced in a country.

3 Policy Scenarios

The *forecast* scenario represents a world in which no additional climate policies are implemented. Therefore, the main model parameters, i.e. GDP, population and emissions are calibrated on the current policies scenario as defined in the World Energy Outlook 2010 (IEA, 2010). In particular world population is expected to reach 7.6 billion in 2020 and global GDP growth is expected to evolve at an average rate of 4% between 2010 and 2020. As a result, world CO_2 emissions in the *forecast* scenario increase by 16% to 35.2Gt CO_2 between 2012 and 2020. For the analysis we implement three policy scenarios: a *base case* and two scenarios with sectoral targets.

3.1 Description of policy scenarios

In the *base case* scenario, all countries face two emission reduction targets for 2020, one for all ETS sectors and one for the non-ETS sectors. Trading of certificates between countries is not allowed except for the EU Member States and within ETS sectors. Since trading emission certificates across ETS and non-ETS sectors and also between regions is restricted, global costs to achieve a given reduction target will not be minimized. The *base scenario* serves as reference scenario.

In the *sectoral targets* scenario, the ETS emission reduction target is further disaggregated into two targets: one for the steel sector (sectoral targets) and one for the remaining ETS sectors. Hence, each country faces three targets (steel, ETS^{-s}, non-ETS sectors). In this scenario, trading of certificates is allowed between steel sectors across all world regions as well as again within EU ETS^{-s} sectors and across EU countries, but not for non-EU countries.

The *linked markets* scenario includes the same targets as the *sectoral targets* scenario. Compared to the *sectoral targets* scenario, the linked markets scenario also allows certificate trading between the steel market and ETS sectors across all world regions. Because of arbitrage, the price of certificates in both markets will be the same. The linking between the ETS sectors and the steel market is meant to reduce overall costs of emission reductions by providing greater flexibility to meet the targets. To avoid double-counting of emission reductions, each ton of CO_2 reduced can only be accounted towards one of the two targets. Since non-ETS sectors are not allowed to trade certificates, the linked markets scenario will not minimize global mitigation costs. An overview on the scenarios implemented in order to analyse sectoral targets is provided inTable 1.

Table 1: Policy scenario definitions

		Targets			Trading options
Scenario	Country group	Steel	ETS	non-ETS & non-Steel	
base case	EU		x	x	EU ETS <-->;
	other AI		x	x	
	NAI		x	x	
sectoral targets	EU	x	x	x	EU ETS <-->;
	other AI	x	x	x	global steel <-->;
	NAI	x	x	x	
linked markets	EU	x	x	x	global ETS <-->;
	other AI	x	x	x	global steel <-->;
	NAI	x	x	x	global ETS <--> global steel;

3.2 Emission targets

The three policy scenarios not only differ by the rules for emissions certificate trading, but also by the number of targets per region. Our analysis ranges from 2012 to 2020, i.e. corresponding to the time frame of the second Kyoto Protocol commitment period.

Abstracting from the dichotomy between developed and developing countries under the Kyoto Protocol, we apply targets for Annex I as well as non-Annex I countries. But the level of ambition of the targets for Annex I and non-Annex I countries differs. For Annex I countries, we assume that national CO_2 emissions in 2020 will be 30% below 1990 levels. This level is consistent with the reduction range for Annex I countries emphasized by the IPCC for meeting the 2°C target and with suggestions by the European Commission (e.g. Gupta et al. 2007, European Commission, 2009)[5]. For non-Annex I countries, the level of ambition is set to 15% below forecast levels in 2020. It represents the lower end of the 15-30% below baseline reduction range generally considered as emission targets for non-Annex I countries which are compatible with the 2°C target (e.g. den Elzen and Höhne 2008). A similar set of targets has also been employed by Duscha et al. (2014), Duscha and Schleich (2013) or Peterson et al (2011).

To split the national target into one for the ETS sectors and one for the non-ETS sectors we follow the EU approach for all countries and require 3/5 of total emission reductions between 2005 and 2020 in the ETS sectors and 2/5 in the non-ETS sectors. This EU approach is adopted for all countries. EU member states face an equal national reduction target of 30% below 1990 levels and split of emission reductions between ETS and non-ETS sectors is 3/5 to 2/5. In all countries, the steel sector needs to reduce emission in 2020 by 10% below forecast. Then the reduction targets for the ETS^{-s} sectors and the non-ETS sectors are determined such that (i) the national ambition level is met and (ii) the above rule for the split between the ETS sectors (i.e. steel + ETS^{-s} sectors) and the non-ETS sectors is maintained. The national emission targets for the three policy scenarios together with the emissions in the *forecast* scenario are displayed in Table 2.

Table 2: CO_2 emission targets by region for 2020

			Policy scenarios		
	2012	Forecast	Base case	Sectoral targets	Linked markets
	Mt	Mt	Percent change		
China	8,084	10,463	-15%	-15%	-15%
Japan	1,086	1,133	-34%	-34%	-34%
India	1,745	2,267	-15%	-1%	-15%
USA	5,455	5,491	-38%	-38%	-38%
Brazil	424	540	-15%	-15%	-15%
EU 27	3,728	3,857	-27%	-27%	-27%
Russia	1,643	1,785	-15%	-15%	-15%
AI	13,621	14,193	-31%	-31%	-31%
NAI	16,641	21,029	-15%	-15%	-15%
World	30,263	35,222	-21%	-21%	-21%

Source: POLES Forecast.

[5] Thus, we do not derive emission targets from actual policy targets, such as the reduction targets committed to under the second Kyoto Protocol period or the countries' pledges made under the Copenhagen Accord and Cancun Agreements. First, these "Pledges" lack ambition, and are unlikely to be consistent with meeting the 2°C target (e.g. Rogelj et al. 2010, Wicke et al. 2010). Second, their economic impacts are limited (see e.g. Peterson et al. 2011, Dellink et al. 2011, Saveyn et al. 2011). Third, the "Pledges" targets of non-Annex I countries are hard to quantify (e.g. discussion in Section 2 of Peterson et al. 2011). Last but not least, it is not the prime objective of this study to portray actual climate policy implementations but rather to explore and highlight implications of sectoral targets.

The base year of the model simulations is 2012. The underlying GTAP data base, whose base year is 2004, is updated to 2012 using observed changes in GDP, CO_2 emissions, and population in each region in the model for the 2004 to 2012 period. These observed changes are treated as “exogenous” variables in the update simulation such that the GDP and emission values in the updated data match their observed values. In the update simulation, we also assume that all Annex I countries meet their national targets under the Kyoto Protocol, with the exception of the USA. We also do not allow for “hot air” for Russia or the Ukraine, so no national targets are imposed for the USA, Russia and the Ukraine in the update simulation.

The model is solved for the 2012 to 2020 time period in two four year periods. All emission reduction targets are applied equally across both periods. A four-year time period is used because we assume that imposing emission reduction targets globally requires a period of adjustment in most markets longer than one year. In particular, with significant capital investment required in many of the energy intensive industries, an adjustment period longer than a single year may be expected. While the choice of a four-year period is arbitrary, we assume that it would be more likely for all market adjustments to changes in emission targets to be completed in four years versus a two-year interval. A three-year time period was not considered because it would yield unequal length time intervals.

Our reduction targets do not account for emission changes from LULUCF, from deforestation and degradation (REDD) or from deforestation and degradation, conservation of existing carbon stocks and enhancement of carbon stocks (REDD-plus).

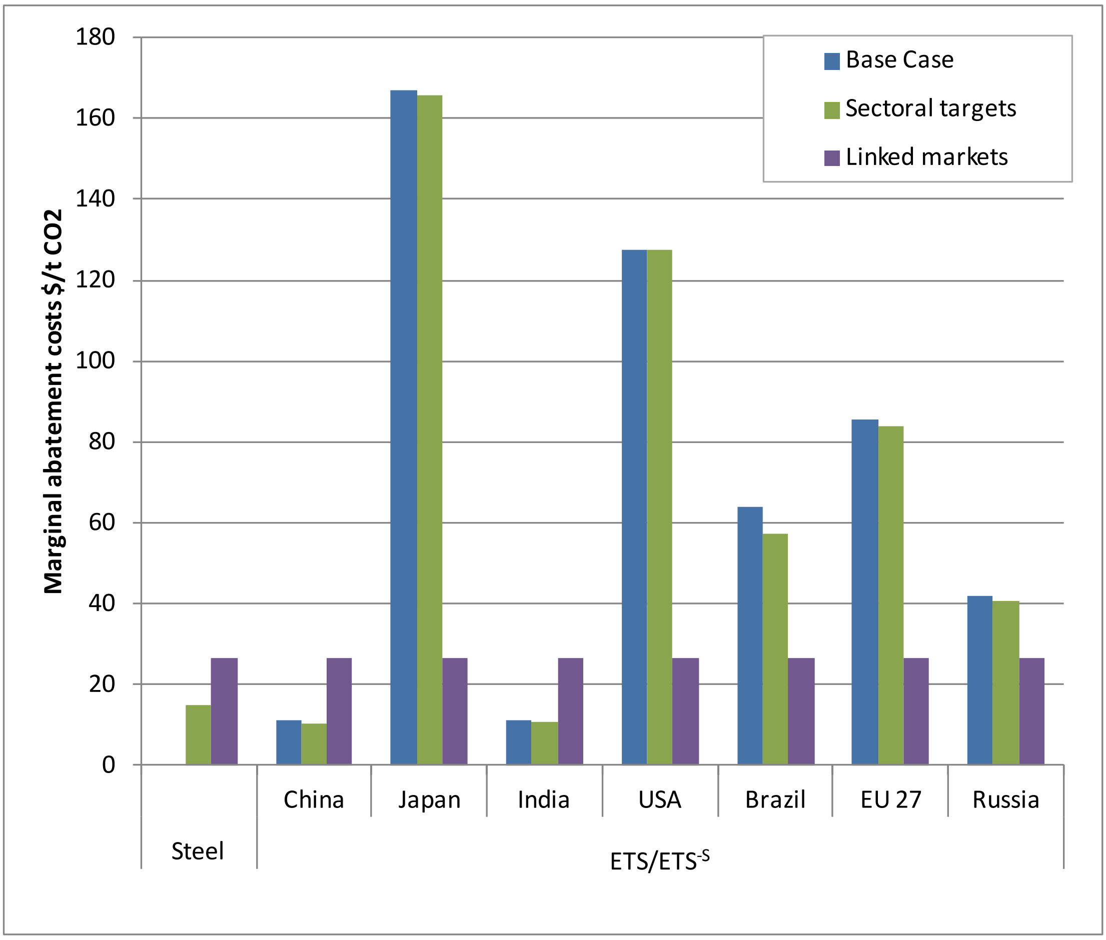
International emission trading (i.e. trade between countries) is not allowed in any scenario. Rules for certificate trading for the ETS sectors and the steel sector vary between the different policy scenarios and are defined in the next subsection. Additional credit trade options as e.g. the CDM or JI are not implemented. To meet national, non-ETS or non-steel targets, countries employ a national CO_2 price, i.e. reductions are realized where they are most cost-efficient within a country’s economy.

4 Results

4.1 CO_2 certificate prices in the policy scenarios

For policy scenarios involving several targets and markets, countries may face more than one CO_2 price (i.e. marginal costs of meeting the emission targets). Figure 2 shows the CO_2 prices for the steel sector and the ETS/ ETS^{-s} sectors in the different policy scenarios for major steel producing countries and world regions in 2020.[6]

Figure 2: CO_2 prices for steel and ETS/ETS^{-s} sectors in the policy scenarios in 2020



In the *base case*, countries face a country specific uniform CO_2 price for the steel sector and for ETS^{-s}. Prices are lowest in China and India at around 11$/t CO_2. Japan (167$/t CO_2), followed by the USA (127$/t CO_2) and the EU 27 (86$/t CO_2) face the highest CO_2 prices in the base case. The different prices reflect that, at the margin, the level of ambition of the emission targets differ significantly between countries and are particularly lenient for China and India, and particularly ambitious for Japan and the USA.

In the *sectoral targets* and the *linked markets* scenarios, each country faces an additional price for certificates in the steel market compared to the base case. By design, this price is the same across all countries. It amounts to 15$/t CO_2 in the *sectoral targets* scenario. Hence, in all countries but China and India, carbon prices for the steel sector are lower in the *sectoral targets* scenario than in the *base case*. At the same time, while in all countries carbon prices in ETS^{-s} are slightly lower than in the base case, they are significantly above the CO_2 prices for the steel sector, with the exception of China and India. The price decreases in ETS^{-s} in most countries reflects that the mitigation potential

[6] To save space we need to limit the presentation of the findings. All simulation results are available from the authors upon request.

in the steel sector is rather high-cost compared to other mitigation options in the ETS^{-s} sectors. Emission reductions in the power sector are particularly cost efficient. Finally, the large variation in CO_2 prices in Figure 2 across regions also shows that in the *base case,* climate policy is asymmetric, i.e. environmental stringency and economic effects of emission targets differ across regions.

In the *linked markets* scenario, the CO_2 price is the same across the ETS^{-s} sectors in all countries (27$/t CO_2) and - because of arbitrage - also equals the CO_2 price for the steel sector. As a result, countries with high marginal abatement costs in the ETS^{-S} markets like Japan, the USA and the EU benefit from the option to buy much cheaper emission certificates from countries with high abatement potential at lower costs like China and India.

4.2 Effects of implementing a price for CO_2 emission for the steel sectors

Implementing emission targets involves a direct and indirect effect on the production costs for BOF and EAF steel industries. The direct effect is an increase in input costs for all fossil fuel inputs. In case of BOF steel, coal and coal products such as coke and coking coal are important inputs. Imposing a price for CO_2 emissions will directly increase the cost of these inputs. The indirect effect is an increase in the price of other intermediate inputs used by the steel sector that are produced by industries that use fossil fuels intensively and are also subject to a carbon price. For example, electricity is the main energy input used in the production of EAF steel. The greater the reliance on fossil fuels in electricity generation or the larger the emission reduction target for the ETS sector (which includes electricity) in a country or region, the larger the indirect effect on production costs for the EAF steel industry.

In addition to the effect on production costs, a specific emission target for the steel sector will affect BOF and EAF industries differently since BOF steel is much more CO_2-intensive than EAF steel. This implies that the majority of the emission reductions in the steel sector will be achieved through a reduction in emissions from the BOF steel industry. In the sectoral targets policy scenario, for example, approximately 90 percent of the total CO_2 emission reductions in the steel sector is achieved through a reduction in emissions from the BOF steel industry. Firms in the BOF steel industry can achieve these emission reductions via two avenues: a reduction in output and a reduction in the per-unit use of fossil fuels. As shown in Figure 1, substitution between energy inputs, between capital and energy, and between the capital/energy composite and other primary factor inputs is possible in the model. As will be shown in section 4.2.2 below, the ability to substitute away from energy inputs as the prices increase due to the imposition of emission targets, plays a significant role in achieving emission reductions in the steel sector.

Besides these carbon price effects, several other factors also affect the production of steel: (i) the "own-use effect", (ii) "domestic demand effect", (iii) "trade effects", and (iv) other "general equilibrium effects"[7]. These effects have different orders of magnitude across countries, counterbalance or amplify each other, and their combined impact may amplify or offset the direct and indirect carbon price effects.

The "own-use effect" exists because scrap is an important input in steel production, in particular for EAF but also for BOF steel. In the model, scrap is part of the steel sectors. In our case, BOF production uses BOF steel as input while EAF production uses EAF steel. As a result, an increase in BOF (EAF) steel prices further increases production costs, while a decrease in steel prices further lowers production costs due to a decrease in factor costs for steel.

Besides the own-use of steel in the steel production, steel is also an important intermediate input in other industry sectors, in particular other manufacturing sectors. Changes in the price of steel as well as changes in

[7] To the extent that EAF and BOF are substitutes on the goods market, there would also be an additional "substitution" effect. Since EAF steel is less CO_2-intensive than BOF steel (even when including indirect CO_2 emissions), a higher CO_2 prices would induce substitution of BOF steel by EAF steel. In practice though, substitution between EAF and BOF steel is (still) rather limited and hence not modeled in our analysis.

CO_2 prices affecting the steel-demanding sectors result in changes in the demand of steel as intermediate input from domestic firms ("domestic demand effect").

"Trade effects" occur because steel is traded intensively across regions because of differences in costs and tastes. The magnitude of the direct and indirect effects of CO_2 prices varies across countries. An extreme example is the production of EAF steel in Brazil and China. In Brazil, the CO_2-intensity of electricity is close to zero due to the large share of hydro power in the Brazilian power mix. Hence, a change in the CO_2 price for the power sector hardly affects the price of electricity or EAF steel production. In contrast, since coal-fired power plants constitute an important factor in China's power generation, its power mix is rather CO_2-intensive. As a result, EAF steel production in China is much more sensitive to the price of CO_2 than in Brazil. In general, countries, where steel production is less CO_2-intensive (directly and indirectly), enjoy a comparative advantage compared to countries with a high CO_2-intensity in steel production. At the same time, countries with a lower CO_2 price for the power sector enjoy a comparative advantage in EAF steel production compared to countries with a higher CO_2 price for the power sector

Finally, general equilibrium effects capture changes in supply and demand in response to price changes. For example, higher CO_2 prices result in a decrease in the total demand for carbon-intensive fossil fuels. As a result, prices for fossil fuels can decrease, offsetting part of the price increase due to the higher CO_2 prices. A less obvious general equilibrium effect is found if due to higher CO_2 prices industry output in a country decreases, lowering the demand for capital and labor in the industry sectors. As a result costs for these factors decrease and, in turn, factor costs for capital and labor in the industry go down, lowering total production costs.

Figure 3 and Figure 4 show the combined effects of implementing the policy scenarios on the output of BOF and EAF steel production for countries and regions with a major share in world steel production.

Figure 3: Changes in BOF steel production in 2020 in different policy scenarios

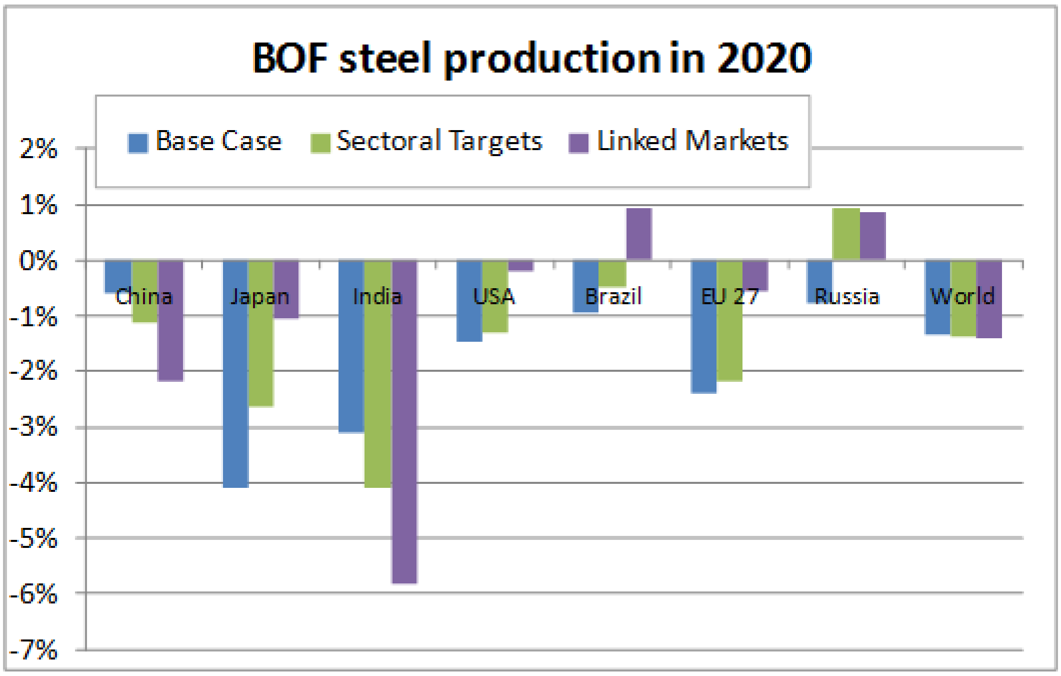
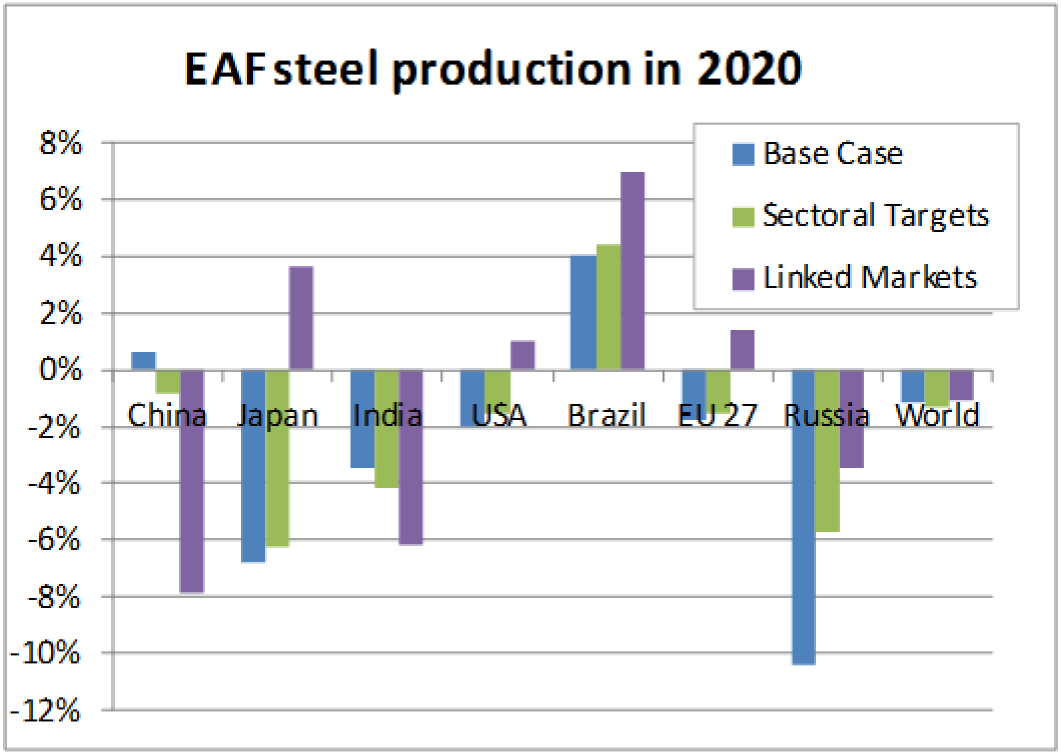


Figure 4: Changes in EAF steel production in 2020 in different policy scenarios



4.2.1 Base case

BOF

In the *base case*, implementing a carbon price results in a decrease in BOF steel production in most major steel producing countries compared to the *forecast* without a carbon price (compare Table 3). The exception is a slight increase in BOF steel production in the United Kingdom. Total world production of BOF steel decreases by 1.3% compared to the forecasted 64.4% increase in BOF production without a carbon price.

Most of the major BOF steel producing countries do not export a large share of their output. Over 90% of BOF steel production is used as an intermediate input by domestic firms in India, Japan, China, and the USA. Across these countries, the main intermediate uses of BOF steel are by the other manufacturing sectors, as own-use by the BOF steel industry, and to a lesser extent by the energy producing sectors. The magnitude of the reduction in BOF production thus depends on the magnitude of changes in production in other manufacturing and the own-use share of BOF steel.

For example, in India, output of other manufacturing sectors decreases by 3.6% compared to the *forecast*, mainly as a result of a reduction in exports due to a relatively large increase in the price of Indian other manufactured products relative to other exporters. Coupled with a reduction in own-use in the BOF steel production, this leads to a 3.1% reduction in Indian BOF steel production compared to the *forecast*. Conversely, a smaller 1.4% reduction in Chinese other manufacturing production limits the reduction in Chinese BOF steel production to 0.6%. For Japan, a relatively large own-use share of BOF steel magnifies reduction in domestic intermediate use by the other manufacturing sectors and refined petroleum industries, leading to a relatively large 4.1% reduction in Japanese BOF steel production compared to the *forecast*. In the USA, a relatively small own-use share of BOF steel helps to mitigate reduction in domestic intermediate demand by other manufacturing and the energy sectors, resulting in a 1.5% reduction in BOF steel production.

To BOF steel producers in Brazil, the EU27 and Russia export markets are more important. For Brazil, approximately 15% of BOF steel production is exported. The increase in the price of energy commodities and BOF steel (through its own-use), leads to a 1.7% increase in the price of Brazilian BOF steel. However, since the global aggregate export price of steel increases by only 1.2%, Brazilian BOF steel exports decline by 4.0%. This reduction in exports offsets the increase in intermediate use of Brazilian BOF steel by the Brazilian other manufacturing industry, leading to a 0.9% reduction in Brazilian BOF steel production compared to the *forecast*. For Russia, which exports over half of its BOF steel production, the 0.7% reduction in BOF steel production is driven by a decline in domestic demand. Even though the Russian BOF steel industry is more energy-intensive than most other BOF steel producers, reductions in the cost of labor and capital from the imposition of the carbon price help offset the increase in the cost of energy inputs, resulting in only a 1.0% increase in the Russian price of BOF steel. But since this price change is close to the average increase in the global export price of BOF steel, Russian BOF exports only increase by 0.1%. However, domestic intermediate demand for Russian BOF steel decreases by 2.0%, mainly from other manufacturing sectors, services, and the energy commodities. Thus, the production of Russian BOF steel decreases by 0.7% compared to the *forecast*.

In the aggregate, export markets are an important source of demand for EU27 BOF steel producers with nearly 30% of total production being exported. This share varies across the EU regions in our model from approximately 8.5% for Italy to nearly 60% for the BOF15 aggregate region (Austria, Belgium, Netherlands, and Sweden). Approximately 70% of BOF steel exports go to other EU member states.

Given the importance of trade, changes in energy costs are a key determinant to relative price changes across EU27 regions in the model. Regions with the most energy-intensive steel production, BOF12 (Czech Republic, Hungary, Poland, Romania, and Slovakia), Spain and Italy, experience the largest increases in the price of BOF steel and the largest reductions in exports (see Table 3). Regions that are the least energy-intensive, France and BOF15 have relatively small price increases and therefore increased exports. Even though BOF steel production in the United Kingdom (UK) has an “average” energy-intensity, reductions in labor and capital costs help offset the increase in the cost of energy inputs and give the UK the lowest BOF steel price increase. With the exception of the UK and the BOF15, all other EU27 regions experience a reduction in domestic intermediate demand for BOF steel, mainly from other manufacturing sectors and BOF steel own-use. For France, this decrease in domestic demand offsets the increase in exports, leading to a decrease of 0.3% in French BOF steel production.

Table 3: Changes in BOF Steel Price and Output

Region	Percentage Change in			
	Intermediate Use	Exports	Output	Price
China	-0.7	5.4	-0.6	0.0
Japan	-3.0	-14.7	-4.1	3.8
India	-3.0	-2.5	-3.1	1.5
USA	-1.5	-0.8	-1.5	1.9
Brazil	-0.5	-4.0	-0.9	1.7
Russia	-2.0	0.1	-0.7	1.0
France	-0.5	0.8	-0.3	1.1
Germany	-1.3	-2.4	-1.5	1.8
Italy	-3.0	-10.0	-3.6	3.2
Spain	-3.1	-5.6	-3.7	2.2
United Kingdom	0.7	3.0	1.3	0.6
BOF15[a]	0.7	1.4	1.1	1.1
REU15	-2.9	-3.3	-3.1	1.8
BOF12	-7.0	-17.9	-11.1	5.4
REU12	-2.5	-1.0	-2.2	1.3

[a] The BOF15 region contains Austria, Belgium, Netherlands, and Sweden; the REU15 region contains Denmark, Finland, Greece, Ireland, Luxembourg, and Portugal; the BOF12 region contains the Czech Republic, Hungary, Poland, Romania, and Slovakia; and the REU 12 region contains Bulgaria, Cyprus, Estonia, Latvia, Lithuania, Malta, and Slovenia.

EAF

The impact of implementing a carbon price on the EAF steel sector is quite different than for the BOF steel sector for two reasons. First, the indirect effect of carbon prices on the price of electricity is much more important for EAF steel production than for BOF steel production. Second, trade effects are much more important for EAF than for BOF steel because globally, about 26% of EAF steel production is exported compared with about 14% of BOF steel production. Thus, regions whose EAF steel industry is not as energy intensive and/or whose electricity sector is not as CO_2-intensive will be able to increase their exports of EAF steel while regions with more energy intensive EAF and/or CO_2-intensive electricity sectors will see their EAF steel exports decline. Further, it may be possible that an expansion in exports will offset declines in domestic intermediate demand for EAF steel by other manufacturing or other industry sectors. While global production of EAF steel decreases by 1.1%, EAF steel production increases in 18 of the 32 regions in the model compared to the *forecast*.

India and the USA are the two major EAF steel producers that are least affected by export markets, with only about 10% of their EAF steel production being exported. Thus, changes in domestic intermediate demand are the main determinant of the change in EAF steel production in these two regions. For India, domestic intermediate use of EAF steel declines by 3.4%, mainly from other manufacturing sectors and own-use in EAF steel production. For the USA, domestic intermediate use decreases by 1.8%, mainly from reductions in use by the US energy industries (coal, oil, and gas) and own-use. Exports of EAF steel decrease in both regions, 3.9% in India and 3.1% in the USA, as a result of relatively large increases in the price of EAF steel. For India, the EAF steel price increases by 3.6%, compared with a 3.0% increase in the global price of EAF steel, due to a more intensive use of energy inputs and own-use. While EAF steel production in the USA is less energy and own-use intensive, a relatively large 33.3% increase in the price of electricity used in EAF steel production leads to a 4.5% increase in the US EAF steel prices. The large increase in the US electricity price is due to a higher carbon price in the USA as well as the US electricity sector being relatively more reliant on coal than other regions in the model.8

EAF steel prices in Russia and Japan also increase by relatively large amounts; 6.2% and 5.2% respectively. In Russia, relatively intensive use of electricity and natural gas, whose prices increase by 14.4% and 18.0% respectively, are the major contributors to the price increase. In Japan, relative intensive own-use of EAF steel and 14.1% increase in the price of electricity are the main contributors to the price increase. Exports decline by 13.9% for Russian EAF steel and by 10.2% for Japanese EAF steel. In addition, domestic intermediate use of EAF steel also decreases by 7.7% in Russia and 5.3% in Japan, mainly due to a reduction in own-use. Thus, the reduction in EAF exports leads to a reduction in own-use in these regions, enhancing the reduction in EAF steel production compared to the *forecast*.

In Brazil and China, EAF steel production increases by 4.0% and 0.6% respectively compared to the *forecast*. In Brazil, the low carbon intensity of the electricity sector implies that the price of electricity in Brazil is not greatly affected by the imposition of carbon prices. The price of electricity paid by Brazilian EAF steel producers only increases by 0.4%. Overall, the price of Brazilian EAF steel increases by 1.4%, or about one-half of the 3.0% increase in the global average price of EAF steel. This leads to an 8.1% increase in EAF steel exports from Brazil. In China, even though electricity production is relatively coal intensive, the lower carbon price in China limits the increase in the price of electricity to 10.9%, which is a smaller increase than in other major EAF producing regions. Thus, the price of Chinese EAF steel increases by only 2.4%, slightly less than the global average, and Chinese EAF steel exports increase by 2.3%. However, reductions in domestic intermediate demand by other manufacturing sectors and the energy industries keep domestic use almost constant.

In the EU27, total EAF steel production decreases by 1.7% compared to the *forecast*. However, as with BOF steel, there are compositional changes in regional EAF production within the EU27. With nearly half of the EU27 production of EAF steel being exported, relative changes in the EAF steel price between regions within the EU drives the changes in regional production. As shown in Table 4, France has the lowest price increase for EAF steel of 1.8% due to a relatively low energy share in EAF steel production and a relatively small increase in the price of electricity in France. The UK, BOF15, REU15, and REU12 also have price increases lower than the global average increase of 3.0%. In the UK, REU15, and REU12 this is the result of relatively low energy intensity in EAF steel production. However, the larger increases in the price of electricity in those regions lead to larger EAF steel price increases relative to France. For the BOF15, a relatively small increase in the price of electricity helps to offset a higher energy intensity in EAF steel production in that region. All of these regions experience an increase in EAF exports due to relatively small increases in their EAF steel prices. Because of the importance of own-use in EAF steel production, an increase in exports will often also lead to an increase in domestic intermediate use. This is the case for France, the UK, BOF15, and REU15. However, for the REU12, the increase in exports is not enough to offset a reduction in EAF steel use by other manufacturing sectors. Conversely, all other regions in the EU27 experience a reduction in EAF steel exports, due to relatively large price increases. As a result they also experience a reduction in domestic intermediate use, primarily due to a reduction in the own-use of EAF steel.

[8] Recent developments in the electricity sector in the USA due to the large amounts of shale gas have not yet been taken into account in the GTAP 7 database.

Table 4: Changes in EAF Steel Price and Output

Region	Energy Share	Electricity Price	EAF Price	Intermediate Input	Exports	Output
	Percentage Change					
China	0.12	10.9	2.4	0.1	2.3	0.6
Japan	0.15	14.0	5.2	-5.3	-10.2	-6.7
India	0.14	6.5	3.6	-0.4	-4.0	-3.4
USA	0.10	33.3	4.5	-1.8	-3.2	-2.0
Brazil	0.25	0.3	1.4	2.4	8.1	4.0
Russia	0.37	14.4	6.2	-7.7	-13.9	-10.4
France	0.07	3.3	1.8	3.3	5.9	4.6
Germany	0.15	12.9	4.0	-4.7	-4.2	-4.3
Italy	0.19	10.9	4.6	-4.9	-7.7	-6.5
Spain	0.10	14.0	3.0	-1.7	-0.5	-1.5
United Kingdom	0.09	14.2	2.6	0.7	3.4	1.5
BOF15[a]	0.11	6.4	2.7	0.6	1.4	1.1
REU15	0.07	13.7	2.1	1.1	4.2	2.5
BOF12	0.26	20.3	8.4	-11.6	-22.4	-15.6
REU12	0.05	17.7	2.9	-2.4	0.4	-1.8

[a] The BOF15 region contains Austria, Belgium, Netherlands, and Sweden; the REU15 region contains Denmark, Finland, Greece, Ireland, Luxembourg, and Portugal; the BOF12 region contains the Czech Republic, Hungary, Poland, Romania, and Slovakia; and the REU 12 region contains Bulgaria, Cyprus, Estonia, Latvia, Lithuania, Malta, and Slovenia.

4.2.2 Sectoral targets

In the *sectoral targets* scenario, the steel industries are separated from the other ETS industries and given their own emission reduction targets. In addition, certificates for the steel sector can be traded globally, leading to a single carbon price for all steel producers. Since certificates for the ETS sector are not allowed to be traded in the *base case*, the carbon price faced by steel producers varies across regions and for most regions is much higher in the *base case* compared to the *sectoral targets* scenario. The main exceptions are China and India, where certificate prices for the ETS sectors (i.e. including the steel industries) in the *base case* are relatively low. In both regions, the carbon price for the steel industries increases from 11.19$/t for China and 11.22$/t for India to the global price of 14.93$/t CO_2.

The emission targets for the steel sector are more ambitious in the *sectoral targets* scenario as compared with the *base case*. Global emissions from the steel sector are approximately 116Mt of CO_2 lower compared to the *base case*. The main reductions in CO_2 emissions compared to the *base case* occur in China and India.

BOF

Because of the higher carbon prices in China and India the price of BOF steel produced in China and India increases more than compared with the *base case*. In China, the price of BOF steel increases by 0.5%, compared with no change in the *base case*. For India, the price of BOF steel increases by 2.1% compared with a 1.5% increase in the *base case*. The increase in the world export price of BOF steel is 0.5% in the *sectoral targets* scenario and hence lower compared with a 1.2% increase in the *base case*. Thus, while BOF steel in China and India is not trade intensive, producers in both regions lose export competitiveness in this scenario. Chinese exports now decrease by 1.4%, compared with a 5.4% increase in the *base case*. The reduction in Indian BOF steel exports is more than twice as large - 4.2% in the base case compared to 9.8% in this scenario. Because of the importance of own-use in the production of steel, the loss of exports further reduces the domestic intermediate demand for BOF steel in China and India. Overall, Chinese production of BOF steel declines by 1.1%, 0.5 percentage points more than in the *base case*, while Indian production declines by 4.1%, one percentage point more than in the *base case*.

In the other major BOF steel producing regions, the carbon price is substantially lower compared to the *base case*. For Brazil, the USA, and Japan, the price increase in BOF steel is 1.0, 1.3, and 2.0 percentage points lower than in the *base case*. In Brazil and Japan, a smaller price increase translates into a smaller loss of export competitiveness, with a 1.5 and 7.0 percentage points smaller decrease in exports respectively. The overall reduction in BOF steel production is 0.4 and 1.4 percentage points lower in Brazil and Japan. Since a major export market for the US BOF steel is Canada, whose steel producers face an extremely large carbon price in the *base case*, US exports of BOF steel decline by 1.5% compared with a 0.8% reduction in the *base case*. However, a smaller reduction in domestic intermediate use by other manufacturing sectors leads to a smaller reduction in total intermediate use and total BOF steel production in the USA from 1.5% in the *base case* to 1.3% in the *sectoral targets* scenario.

In Russia, the carbon price facing BOF steel producer declined from 42.1$/t in the *base case* to 14.93$/t in the *sectoral targets* scenario. With a lower carbon price, the price of Russian BOF steel now decreases by 0.2% below the *forecast*, compared with a 1.0% increase in the *base case*. This occurs because the (compared to the *base case* significantly lower) CO_2 price only partly offsets the decrease in the market prices of oil, natural gas and refined petroleum products. Those prices decrease as a result of a decrease in global demand for those products due to the introduction of a CO_2 price. The BOF steel price decrease enhances Russia's export competitiveness, with Russian BOF exports increasing by 2.3% compared with a 0.1% increase in the *base case*. Overall, Russian BOF steel production increases by 0.9% compared with a 0.7% decrease in the *base case*.

For the EU27 regions, the lower carbon price for BOF steel producers compared to the *base case* also leads to smaller price increases. The largest price decreases compared to the *base case* occur for the regions with the most energy-intensive production: Italy, Spain, and the BOF12. Since most BOF exports from EU27 regions are intra-EU, the energy-intensive regions do not lose as much competitive advantage as compared to the *base case*. Italy and the BOF12 have much smaller declines in exports compared to the *base case* while Spanish BOF exports actually increase in this scenario not only compared to the *base case* but also compared to the *forecast*. These three regions also have smaller reductions in BOF steel production in this scenario, as compared to the *base case*. For the EU27 regions with less energy-intensive BOF production, smaller price decreases relative to the energy-intensive regions imply either a smaller gain or a larger reduction in exports. The gain in BOF exports for producer in the United Kingdom and the BOF15 drop significantly, from 3.0% to 0.3% for the UK and 1.4% to no change for the BOF15. Overall, BOF steel production still increases in these two regions, but the increase is a full percentage point lower. BOF steel producers in France, Germany, the REU15, and the REU12, experience larger reductions in export sales in this scenario compared to the *base case*, and larger reductions in total BOF steel production. Overall, the drop in aggregate BOF steel production in all EU27 regions is slightly smaller, at 2.1%, compared with a 2.3% reduction in the *base case*.

EAF

While EAF steel production has lower direct CO_2 emissions than BOF steel production, the relative changes in carbon prices still have significant effects on EAF steel production across regions. China and India both have substantial reductions in EAF steel production in this scenario compared with the *base case*. For China, EAF steel production declines by 0.8% compared with a 0.6% increase in the *base case*, while India experiences an even larger production decrease of 4.2% compared with a 3.5% reduction in the *base case*. What is driving both of these reductions in production is a loss of EAF exports from changes in relative EAF steel prices. Even though the carbon price faced by EAF producers in China and India increases in this scenario compared to the *base case*, the carbon price for the ETS sectors in both regions decreases slightly. Thus, the price of electricity used in EAF steel production in China and India also declines slightly. Given the importance of electricity in EAF steel production, the price of EAF steel declines by 0.1 percentage points in both China and India, to 2.3% and 3.5%, compared to the *base case*. However, because of larger reductions in the carbon price faced by EAF producers in other regions, the aggregate world price of EAF steel decreases by 0.8 percentage points compared to the *base case* resulting in an increase of 0.5% compared to the *forecast*. Since the world price declines by more than the prices of Chinese and Indian EAF steel, EAF exports from China and India both decline compared to the *base case*. For China, EAF steel exports decrease 0.8% compared with a 2.3% increase in the *base case*, while Indian EAF steel exports decrease by 7.1%, compared with a 3.9% decrease in the *base case*. Given the importance of own-use in EAF steel production, this reduction in exports also leads to reductions in domestic intermediate use in both regions.

In all other major EAF producing regions, the relatively large reduction in the carbon prices leads to lower input costs and smaller price increases compared with the *base case*. In Russia, the US, Brazil, and Japan, the price increases are 2.4, 1.8, 1.0, and 0.8 percentage points lower. Since the aggregate global price of EAF steel is 0.8 percentage points lower than the *base case*, these regions either have lower reductions in exports (Russia, US, and Japan) or an increase in exports (Brazil) compared with the *base case*. Hence, the introduction of sectoral targets would decrease the reduction in EAF steel production in Russia, the US, and Japan, while increasing EAF steel production in Brazil, compared to the *base case*.

In the EU27 regions, all regions have smaller increases in the price of EAF steel compared to the *base case*, with the largest changes occurring in the energy-intensive production regions: Germany, Italy, the BOF15, and the BOF12. Again, since most EAF exports from EU27 regions are intra-EU trade, the changes in relative prices between EU27 regions imply that regions with larger price increases will have a smaller loss or larger gain in exports, while the regions with smaller price increases will have a smaller gain or larger loss in exports. Overall, aggregate EAF steel production in the EU27 has a smaller decline of 1.5% compared with a 1.7% decline in the *base case*.

Certificate trading

Table 5 shows the amount of certificates traded on the steel market in the *sectoral targets* scenario. Overall, trade of CO_2 certificates in the steel sector is very limited. Major seller countries are China and India (in BOF steel) which have a large reduction potential as well as the USA (in EAF steel). In all countries, selling emission certificates is not only caused by a significant decrease in CO_2-intensity of the production process, but also by a decrease in production compared to the *base case*. The sectoral targets allow Russia to increase BOF production by purchasing certificates from the steel sectors abroad.

Table 5: CO2-emissions and certificate trading (Mt) in the steel sector in 2020

	CO_2 emissions in the steel sector		Certificate sales (-) and purchases (+)
	base case	sectoral targets	
China	582	518	-5
Japan	41	36	-1
India	101	88	-3
USA	51	43	-3
Brazil	29	27	1
EU 27	77	71	2
Russia	75	71	4

Globally, the decrease in BOF steel production is slightly smaller in the *sectoral targets* scenario, at 1.2%, compared with the 1.3% decrease in the *base case*. Even with a substantial drop in Chinese BOF production, the lower carbon prices faced by BOF steel producers in other regions slightly offsets the reduction in Chinese production. Conversely, there is a slightly larger decrease in global EAF steel production, 1.2% compared with a 1.1% reduction in the *base case*. That is, the losses in Chinese and Indian EAF steel production are not fully offset by increases from other major EAF steel producers.

4.2.3 Linked markets

Linking the steel certificate market and all ETS sectors in a large carbon market allows a more cost-efficient distribution of mitigation actions among countries and sectors. For the steel carbon market the linking results in an increase of certificate prices from 14.93 $/ton in the *sectoral targets* scenario to 26.53 $/ton in the *linked markets* scenario. As a result, the ETS^{-s} sectors meet their emission target by purchasing certificates from the steel sector. In total, about 42Mt additional CO_2 reductions are realized in the steel sector (see Table 6).

There are two effects on the steel industry of linking the carbon markets. First, the carbon price faced by steel producers in all regions increases, compared to the *sectoral targets* scenario. Second, for most regions, the carbon price for the ETS^{-s} sector in most of the major steel producing regions decreases. For those regions, the price of electricity and refined petroleum products used in steel production falls substantially (see Table 7). The exceptions are China and India, which had relatively low carbon prices for the ETS sector in the *sectoral targets* scenario. In the *linked market* scenario, the carbon price for the ETS sector in China and India is approximately 2.5 times higher than in the *sector target* scenario, which leads to substantial increases in the price of electricity.

For both China and India, the higher steel carbon price and higher electricity prices lead to larger increases in the price of BOF and EAF steel in the *linked market* scenario compared with the *sectoral targets* scenario. Because most of the other major steel producing regions have smaller steel price increases (or in some cases price decreases), China and India become less competitive in the steel export markets. Steel exports from China and India decrease stronger in the *linked market* scenario compared to the *sectoral targets* scenario, leading to larger reductions in steel production in both regions.

Japan and the USA have smaller decreases in BOF steel production in *the linked market* scenario compared to the *sectoral targets* scenario. Smaller price increases in BOF steel, due to lower input costs for refined petroleum products and electricity, lead to smaller export losses in Japan. In the US, lower electricity prices lead to greater output in other manufacturing sectors, compared with the *sectoral target*s scenario. This virtually eliminates the drop in domestic intermediate demand for BOF steel in the USA. US exports of BOF steel remain virtually unchanged with a decrease in exports to Canada being offset with export increases to other regions. EAF steel production in Japan and the USA increases in the *linked market* scenario compared with a decrease in the *sectoral targets* scenario due to the substantial reductions in the prices of EAF steel as a result of lower electricity prices, which leads to a growth in exports.

In Brazil, the lower price of electricity leads to the prices of BOF and EAF steel decreasing compared to the *forecast*. Exports of BOF steel increase in the *linked market* scenario compared to a decrease the *sectoral targets* scenario. The growth in BOF exports also causes BOF steel production in Brazil to increase, compared with a decrease in production in the *sectoral targets* scenario. The reduction in the price of EAF steel further enhances Brazilian EAF steel exports and production in the *linked market* scenario compared to the *sectoral targets* scenario.

For Russia, the higher costs of fossil fuel inputs in BOF production, due to the higher carbon price, offsets the reduction in the price of electricity, leaving the change in the price of BOF steel unchanged compared to the *sectoral targets* scenario. Thus, Russian output of BOF steel also remains virtually unchanged. However, the lower price of electricity results in a smaller price increase in Russian EAF steel and a smaller decrease in EAF exports compared to the *sectoral targets* scenario.

The *linked market* scenario has the smallest impact on aggregate BOF steel production in the EU27. Total production decreases by 0.5% compared with a 2.1% decrease and a 2.3% decrease in the *sectoral targets* scenario and *base case*. France, Germany, Italy, REU15, BOF12, and REU12 all have smaller reductions in BOF steel production; the UK and BOF15 have larger increases in production while Spanish production increases, compared to a decrease in the other scenarios. Conversely, the *linked market* scenario has a large positive impact on EAF steel production in the EU27, with aggregate production increasing 1.4% compared to 1.5% and 1.7% decreases in the other scenarios. EAF steel production increases in all EU regions, except for Italy and the BOF12 which have the most energy-intensive production.

Certificate trading

As noted earlier, by linking the steel and ETS markets, steel emission certificates can be sold to either steel producers in other regions or to firms in the ETS sector, located either domestically or in other regions. As shown in Table 6, China and India are major sellers of emission certificates not only in the steel market but also in the ETS market because of their lower marginal abatement costs. In total, China sells about 1260m and India about 247m CO_2 certificates in the *linked markets* scenario. With overall net sales of steel emission certificates to the ETS sector, global steel production must decrease in the *linked markets* scenario compared to the *sectoral targets* scenario. Since BOF steel has more direct emissions than EAF steel, it will bear the majority of the reduction in steel production. Global production of BOF steel declines by 1.5% in the *linked markets* scenario compared to a 1.2% reduction in the *sectoral targets* scenario, while global EAF steel production remains unchanged. Other countries profit from this large supply of emission certificates, in particular the USA where the steel sector becomes a net-buyer of certificates.

Table 6: Certificate trading (Mt) between the ETS and the steel sectors in the linked markets scenario in 2020

	Steel	ETS
China	-42	-1218
Japan	2	174
India	-11	-236
USA	1	818
Brazil	1	8
EU27	4	361
Russia	3	59

+: certificate purchases, -: certificate sells

Table 7: Change in price of electricity used in EAF steel roduction

	Percentage change to forecast		
	Base Case	Sectoral targets	Linked markets
China	10.9	10.4	29.4
Japan	14.1	14.6	2.6
India	6.5	6.4	13.8
USA	33.3	33.8	8.0
Brazil	0.4	0.4	-0.9
Russia	14.4	15.0	8.0
France	3.3	3.4	1.0
Germany	12.9	13.0	4.6
Italy	10.9	11.6	3.4
Spain	14.0	14.3	4.5
United Kingdom	14.2	14.1	4.5
BOF15[a]	6.4	6.5	1.9
REU15	13.7	13.7	4.5
BOF12	20.3	20.6	7.6
REU12	17.7	17.9	6.0

[a] The BOF15 region contains Austria, Belgium, Netherlands, and Sweden; the REU15 region contains Denmark, Finland, Greece, Ireland, Luxembourg, and Portugal; the BOF12 region contains the Czech Republic, Hungary, Poland, Romania, and Slovakia; and the REU 12 region contains Bulgaria, Cyprus, Estonia, Latvia, Lithuania, Malta, and Slovenia.

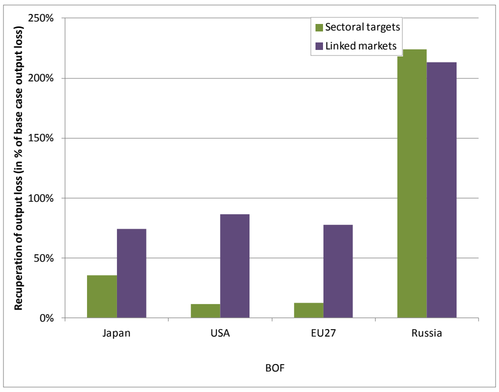
4.2.4 Measuring changes in competitiveness effects of sectoral approaches

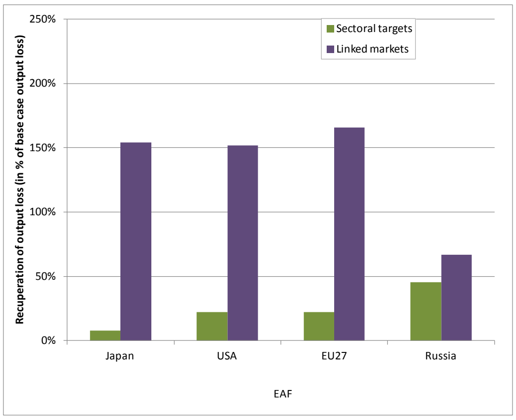
To capture the extent to which sectoral approaches are able to counter the negative effects asymmetric climate policy on steel output we relate the losses in *sectoral* and *linked markets* to the losses in the *base case* (compared to the *forecast*). More specifically, we use the following measure as an indicator:

$$1-\frac{(q_s-q_f)}{(q_b-q_f)}$$

Where q_f, q_b and q_s reflect output in the *forecast*, *base case*, and *sectoral targets* scenarios. For the linked markets scenario, the indicator may be calculated equivalently by replacing output in sectoral targets by output in the linked markets scenario in the formula above. The indicator reflects recovered output loss (in% of output loss *base case* versus *forecast*). An indicator greater than 1 (or 100%) means that *sectoral targets* or *linked markets* more than offset the output loss suffered in the *base case* compared to the *forecast*. We calculate this indicator for BOF and EAF. Figure 5 shows the recovered output loss (in% of output loss base case versus forecast) for the *sectoral targets* and *linked markets* scenarios for BOF and EAF steel. Accordingly, for the countries with the highest CO_2 prices in the *base case,* i.e. Japan, USA, and EU27, *sectoral targets* make up for about 25% and *linked markets* for about 77% (155%) of the production losses for BOF (EAF) of these countries in the *base case*. For BOF and EAF combined the figures are 21% for *sectoral targets* and 105% for *linked markets*. Hence, linking ETS markets across regions turns out to be more effective in terms of countervailing negative competitiveness for the steel sector, but there are substantial differences across steel types and regions. Figure 5 again illustrates that *sectoral targets* and *linked markets* more than offset output losses in the base case for BOF in Russia and EAF in Japan, USA and EU27.

Figure 5: Recuperation of output loss (in % of output loss in base case compared to forecast)





5 Summary and Conclusions

This paper explores the effects of sectoral targets in international climate policy in a macroeconomic framework, their interaction with the EU emissions Trading System (EU ETS), and to which extent sectoral targets can address the concerns of competitiveness. We assume that a global binding agreement exists between the steel sector and governments.

The analyses rely on a multi-country, multi-sector, recursive dynamic CGE model (DYE-CLIP). The model consists of 32 countries/regions and 18 sectors. To better reflect technological realities and to account for different energy and carbon intensities of production, the GTAP sector ferrous metals is disaggregated into two industries, i.e. primary fossil fuel based steel production (BOF) and secondary scrap recycling steel production (EAF) which is mainly based on electricity use. The model simulations target the year 2020. The analysis shows that differentiating industrial technologies in a CGE framework allows to gain additional insights into major economic effects, in particular under climate policies.

Effects take place in terms of *direct and indirect carbon price effects* (the latter more pronounced in the EAF steel sector if carbon policies are applied to the upstream electricity sector), *own-use effect* as scrap is more expensive if production costs for steel rise, *domestic demand effects* as demand for steel as an intermediate input changes due to price changes or due to CO_2-price induced changes in demand for products using steel as intermediate inputs, *trade effects* as direct and indirect carbon price effects affect production costs differently in regions and cause trade patterns to shift (i.e. a high share of renewables in electricity generation in a country such as Brazil results in a comparatively lower indirect carbon price effect) and *general equilibrium effects* which are based on simultaneous adjustment and feedback processes on the demand and supply side within the economy, i.e. effects on global energy prices due to lower demand for energy intensive products under a climate policy. The latter effect is sometimes referred to as “fossil fuel channel of carbon leakage” as a reduction in energy prices in response to a climate policy might stimulate renewed demand and thus lead to an increase in emissions.

Our findings suggest that sectoral approaches, in our case sectoral targets and linking of emission trading schemes, may effectively counter the (negative) output effects of asymmetric climate policy. For the scenarios implemented, linking ETS is substantially more effective than introducing sectoral targets alone. The findings differ, however, by country and steel production technology. In comparison to the *base case*, allowing for global trading on the steel market on the one hand and the linked global emissions market on the other, improves the competitiveness of steel production in Annex I countries with their stringent targets and relatively high marginal abatement costs. For these countries, carbon prices for steel are lower in sectoral targets and even more so in linked markets so that production costs are lower, export competitiveness improves and output is higher than in the *base case*. This effect is reinforced by a reduction in production in China and India which hold large global shares in steel production and face cost increases in response to the trading schemes compared to the *base case*. The effects are more pronounced in the *linked markets* scenario for EAF steel production as production costs are affected by both the direct and indirect carbon price, among others. In comparison to other countries, India and China are negatively affected by sectoral targets and more so by linking markets. They suffer from increased carbon prices both for the steel and the ETS^{-s} sectors compared to the *base case* resulting in a loss of export competitiveness and decreased production and a rise of global steel prices which further strengthens other countries’ competitiveness.

Global effects are more ambiguous as China and India hold large shares of global production and their losses are not fully offset by increases from other major producers. The loss in global BOF production is slightly lower in the sectoral *targets* scenario and slightly higher in the *linked market* scenario compared to the *base case*, driven by the effects in China and India. The effect on global EAF production is less pronounced.

In both cases, China and India sell large amount of emission certificates which result from their decrease in production compared to the *base case* as well as from a decrease in CO_2-intensity of the production process.

In general, these results illustrate that differentiating industrial technologies in a CGE framework allows to gain additional insights into major economic effects in response to climate policies. It allows to address aggregated as well as disaggregated, country and sector specific, effects on production, costs, international competitiveness and the environment.

In this study, we treated EAF and BOF steel as separate products which cannot be substituted for each other. Future modelling could incorporate the increasing substitutability of EAF and BOF steel products due to technological progress, and thus allow for shifts between those processes in response to climate policy.

6 References

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7 Appendix

7.1 Overview of steel production

Table 8: Overview of global crude steel production in 2012

Region	Total production of crude steel (in 1000 tonnes)	Share of global crude steel production	Share of EAF steel
China	716 542	46%	10%
EU27	168 589	11%	42%
EU15	143 846	9%	43%
EU12	24 743	2%	34%
Japan	107 232	7%	23%
USA	88 695	6%	59%
India	77 561	5%	67%
Russia	70 426	5%	27%
Rest Asia	110 397	7%	49%
South America	46 379	3%	35%
CIS excl. Russia	40 529	3%	13%
Other Europe	39 923	3%	74%
North America excl. US	32 913	2%	61%
Middle East	24 679	2%	91%
Africa	15 336	1%	67%
Oceania	5 805	0%	24%
Global	1 545 011		29%

Source: World Steel (2013).

Table 9: Value of Steel Output by Production Process for GTAP v.7 Database

Region	Total	BOF	EAF
	$millions, 2004	%	%
China	175 503	85%	15%
Japan	169 145	74%	26%
South Korea	58 427	56%	44%
India	29 190	56%	44%
USA	131 961	48%	52%
Brazil	24 317	77%	23%
Germany	48 653	69%	31%
Italy	59 330	50%	50%
Russia	25 040	79%	21%
Rest of Annex I	217 342	63%	37%
Rest of non-Annex I	118 233	34%	66%
World	1 057 140	63%	37%

Source: Author's calculations and GTAP v.7 database.

7.2 Disaggregation of the steel sector

For the following analysis, the GTAP sector ferrous metals (i_s) is disaggregated into two industries based on production data from the Steel Statistical Yearbook (Worldsteel) and COMTRADE data (UN). To disaggregate input use by ferrous metals in the GTAP database into inputs used by BOF and EAF steel producers, we employ the following procedure. First, we allocate total input cost[9] for ferrous metals to BOF and EAF steel production based on the production share of BOF and EAF steel in the Steel Statistical Yearbook for 2004 (the base year in the GTAP data). For example, approximately 80% of the steel produced in Australia was from a BOF process. This production share is then multiplied by the total cost of ferrous metal production in Australia in the GTAP database, $12,684.6 million (in 2004), to obtain the total input cost for BOF steel production, $10,161.0 million. The total cost of EAF steel production is then the difference between the total cost for ferrous metals in the GTAP database and the estimated total cost of BOF steel production. Table 9 provides a decomposition of the total cost of ferrous metal production into total input cost for BOF and EAF steel production by region. Next, because BOF produces steel from basic raw materials, all the coal (coa), other minerals (omn), which includes metal ores, refined petroleum and coal products (p_c), which includes coke, used by the ferrous metals sector is allocated to the BOF steel industry.

The use of electricity, gas, labor, and capital in ferrous metals in the GTAP data is allocated to BOF and EAF steel based on estimated cost shares for BOF and EAF processes (www.steelonthenet.com) in 2011. For example, the electricity cost share for BOF steel is 0.0228 while the electricity cost share for EAF steel is 0.0666, implying that BOF uses approximately one-third less electricity than EAF. However, to account for differences in steel production processes used across regions, the ratio of electricity cost shares is multiplied by the ratio of the estimated total input cost for BOF and EAF steel production[10]. Again, using Australia as

9 Total input cost is defined as sum of all intermediate domestic inputs (VDFA) plus all intermediate imported inputs (VIFA) plus EVFA for all primary factors used by ferrous metals in the GTAP database.

10 $VFA_{ely,EAF} = \dfrac{VFA_{ely,i\_s}}{\left(1 + \dfrac{c_{ely,BOF}}{c_{ely,EAF}} \dfrac{TC_{BOF}}{TC_{EAF}}\right)}$ where $VFA_{ely,EAF}$ is the total input cost of electricity for EAF steel in a given region, VFA_{ely,i_s} is total input cost of electricity for ferrous metals in that same region, c_{ely} is the cost share of electricity in BOF or EAF steel production, and TC is the estimated total input cost for BOF and EAF steel production for the same region.

an example, the ferrous metal sector purchased $489.6 million of electricity in the GTAP database. Of this amount, $205.6 million is allocated to EAF steel production with the remainder being allocated to BOF steel production. This approach is also used to allocate natural gas intermediate use between BOF and EAF steel. Similarly, skilled and unskilled labor are allocated to BOF and EAF steel using a variant of the above approach that uses the relative labor cost shares instead of the electricity cost shares and capital is allocated with a variant that uses the relative depreciation rates for BOF and EAF steel production.

Once all coal, other minerals, refined petroleum and coal products, electricity, gas, labor, and capital inputs have been allocated to BOF or EAF steel, the remaining intermediate inputs are allocated on a proportional basis to ensure that the estimated total cost for each production process is met. For example, using the above steps resulted in $5,498.7 million in ferrous metal input use in Australia being allocated to BOF steel production and $728.1 million being allocated to EAF steel production. This leaves an additional $4,662.3 million to be allocated to BOF steel production in order to obtain the total cost estimate of $10,161.0 million. Similarly, an additional $1,795.5 million in input cost must be allocated to EAF steel production in order to meet its total cost target. Thus, approximately 72% [4662.3/(4662.3+1795.5)] of all remaining intermediate inputs used in ferrous metal production in Australia must be allocated to BOF steel production. This share is applied to total cost of all remaining intermediate inputs to ferrous metal production in Australia in the GTAP database.

The export sales of ferrous metal products in the GTAP v.7 database are allocated to BOF and EAF steel products using COMTRADE export data. We identified a list of 4-digit HS codes that are either primarily associated with BOF steel or EAF steel products.[11] Then, the level of ferrous metal product exports in the GTAP database (e.g., VXWD) is disaggregated into BOF and EAF steel product exports based on the observed share of BOF steel exports between a given country bilateral pair in the COMTRADE data.[12] If the COMTRADE data reported zero trade in steel products between a given bilateral country pair but the GTAP data reported a positive value, exports were allocated using the average export share of BOF steel across all bilateral trade pairs.

The domestic sales of ferrous metal products are disaggregated into domestic sales of BOF and EAF steel products using a multiple step procedure. First, sales of ferrous metal products to the private and government households are allocated to BOF and EAF steel products based on the production share of BOF and EAF steel in each region. Next, the sum of the value of exports, sales to the private household, sales to the government household, and own-use (at market prices) are subtracted from the total sales (which equals total cost in perfectly competitive markets) of BOF and EAF steel products to arrive at the total value of sales for domestic intermediate use (e.g., other than own-use) for each type of steel. Using these sales values, we then compute the share of sales for domestic intermediate use accounted for by BOF steel products.[13] Finally, the sale of ferrous metal products for domestic intermediate use, other than own-use, is allocated using the BOF intermediate product sales share. The modeling approach taken reflects the rather limited substitutability of BOF and EAF steel in practice.

[11] The HS codes 2618, 2619, 7201, 7202, 7203, 7205, 7212, 7217, 7219, 7220, 7223, 7225, 7226, and 7229 are associated with BOF steel exports. The HS codes 7204, 7213, 7214, 7215, 7216, 7218, 7221, 7222, 7224, 7227, 7228, and 7301 – 7307 are associated with EAF steel exports.

[12] The COMTRADE data for BOF and EAF steel products was not consistent with the production data from the Steel Statistical Yearbook for Indonesia, the United Kingdom, BOF15, REU15, BOF12, EAF12, Switzerland, Norway, Russia, Egypt, Rest of Annex I countries, rest of developing countries, and rest of least developed countries. For these regions, the trade shares of BOF and EAF steel were set equal to the production shares of BOF and EAF steel for each region.

[13] This share is the value of BOF sales for intermediate use divided by the sum of BOF and EAF sales for intermediate use.