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SECTORAL TARGETS TO ADDRESS COMPETITIVENESS — A CGE ANALYSIS WITH FOCUS ON THE GLOBAL STEEL SECTOR

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In the wake of the Paris Climate Agreement, countries may employ sectoral approaches. These allow for efficiency gains while at the same time addressing the concerns of competitiveness and carbon leakage. Applying a multi-country, multi-sector dynamic CGE model, this paper explores the role of sector emission targets for the steel sector in an international agreement, their interaction with emissions trading systems, and to which extent sector targets may address competitiveness concerns. To better reflect technological realities, the steel sector is disaggregated into its two main industries: primary fossil fuel-based steel production (BOF) and secondary scrap recycling steel production (EAF). The policy simulations suggest that sectoral targets may effectively counter the (negative) output and competitiveness effects of differences in the stringency of climate policy across countries. BOF steel contributes significantly more to emission reductions than EAF steel. Moreover, the output effects of BOF and EAF are of opposite signs.

Keywords: Sectoral targets; steel sector; competitiveness; carbon leakage; climate policy.

1. Introduction

The Paris Agreement (UNFCCC, 2015) allows countries to nationally determine the type of commitment they would undertake. Countries' nationally determined contributions (NDCs) may, for example, involve economy-wide absolute targets, intensity targets, or sectoral targets. Although the Paris Agreement does not directly mention

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carbon markets, it includes provisions that may advance international carbon markets in a post-Kyoto climate regime. In particular, Article 6 of the Paris Agreement recognizes that countries can employ “cooperative approaches” to implement their NDCs, thereby using “internationally transferred mitigation outcomes” (ITMOs). More than half the countries plan using international market mechanisms to meet their NDCs (http://cait.wri.org/indc/). Conceivably, these mechanisms also refer to sector-focussed approaches such as sectoral targets, i.e., the joint binding agreements between sectors and governments of countries (e.g., Baron *et al.*, 2009; Sawa, 2010). Some countries may employ such sectoral targets as a first step toward more ambitions economy-wide targets in the future (see e.g., Den Elzen *et al.*, 2008; Barrett, 2010; Böhringer *et al.*, 2014). Sectoral approaches may also emerge from industry initiatives, including ICAO and IMO. A first example could be the so-called Global Market-Based Measure, a carbon offsetting and reduction scheme for international aviation agreed upon by the ICAO in 2016.

Sectoral targets may lead to ITMOs further on called “emission certificates” being traded across countries, thus allowing for efficiency gains while at the same time addressing the concerns of competitiveness and carbon leakage when the stringency of climate policy differs across countries. Even before the emergence of the Paris Agreement, sectoral targets have been one proposition for future agreements on climate change, having primarily been proposed for energy-intensive sectors, such as the cement, steel, or electricity sectors, but their role may have been strengthened by the new agreement.

Quantitative analyses of sectoral targets for individual sectors are mainly based on partial equilibrium models (e.g., Mathiesen and Maestad, 2004; Meunier and Ponssard, 2012; Karali *et al.*, 2014) but also on computable general equilibrium (CGE) analysis to capture economic effects on trade and production (e.g., Voigt *et al.*, 2011; Hamdi-Cherif *et al.*, 2011; Gavard *et al.*, 2011; Mu *et al.*, 2017).

In this paper, we explore the impacts of emission targets in the steel sector in a general equilibrium framework, their interaction with an emissions trading system (ETS), and to which extent sector targets may address competitiveness concerns. The steel sector seems particularly suited for a sectoral targets approach for two reasons. First, steel production is relatively CO_2-intensive, accounting for about 3–5% of the global CO_2 emissions. Secondly, the steel industry is trade-intensive, with more than a quarter of finished steel products being exported (World Steel Association, 2014).

Steel is mainly produced via two technological routes: a basic oxygen furnace (BOF), which produces primary steel from virgin raw materials, or an electric arc furnace (EAF), which produces secondary steel from recycled metal products. Thus, BOF production is mainly associated with direct CO_2 emissions, whereas EAF causes primarily indirect CO_2 emissions via electricity use. The shares of BOF and EAF differ considerably across countries (see Table A.1).

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 for CGE 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 cannot adequately capture competitiveness and leakage effects.

To explore the implications of sectoral targets for the steel industry, and as the main methodological contribution of the paper, we first modify an existing dynamic CGE model to more adequately reflect steel production technologies. The model is then applied to investigate two 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 target 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 and includes the disaggregation of the steel sector into BOF and EAF steel. Section 3 describes the specific emission targets in each scenario. Section 4 presents the model results. The final section discusses the main findings and concludes.

2. Modeling

2.1. *Empirical model*

The analyses rely on a multi-country, multi-sector, recursive dynamic CGE model which is based on the GDyn (Ianchovichina and McDougall, 2001) and GTAP-E models (Burniaux and Truong, 2002; Nijkamp *et al.*, 2005), utilizes the GTAP 7 database, and includes domestic trade and transport margins (Peterson and Lee, 2009). 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.[1] As is typical for CGE models (e.g., Dellink *et al.*, 2004; Babiker and Eckaus, 2007; Guivarch *et al.*, 2011; Capros *et al.*, 2013; Nordhaus and Sztorc, 2013), 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.[2]

The base year of the model is 2012. The underlying GTAP database, 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 2004–2012 period.[3] In the update

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[1] For example, Babiker and Eckaus (2007), Guivarch *et al.* (2011), or Capros *et al.* (2013) also employ such recursive-dynamic models, whereas Dellink *et al.* (2004) assume perfect foresight. In this case, household's and firms' decisions also take into account utility and profits of all future periods. For further discussion of this assumption in the climate policy context, please see Babiker *et al.* (2009).

[2] In contrast, Babiker and Eckaus (2007) or Guivarch *et al.* (2011) allow for labor market rigidities.

[3] Employing the more recent GTAP v8 database, which uses 2007 as the base year, would also involve updating to a 2012 reference year that we used in the analysis. This would require using the same observed changes in GDP, CO_2 emissions, etc. from 2007 to 2012 that were used when we updated the v7 database. Potential changes in intermediate input use and consumption shares for a given region between 2004 and 2007 should be small, given short three-year difference between the reference years.

simulation, we also assume that all Annex I countries meet their national targets under the Kyoto Protocol, with the exception of the United States. We also do not allow for "hot air" for Russia or the Ukraine, so no national targets are imposed for these regions in the update simulation.

The model consists of 32 country/regions and has 18 industries/sectors[4]. The EU 27 has been aggregated into five countries (France, Germany, Italy, Spain, UK) and four regions according to their main steel-production routes (BOF versus other processes) and their economic development (EU15 versus EU12): BOF 15, BOF 12, REU 15, and REU 12.[5] For the remainder of this paper, we specify two groups of sectors. The ETS sector includes electricity; refined petroleum and coal; chemicals, rubber, and plastic products; other mineral products (cement); paper products; nonferrous metals as well as the BOF and EAF steel industries. Note that these industries/sectors are part of the European Union ETS. All remaining industries/sectors belong to the group of the non-ETS sector. The sub-group $\mathrm{ETS}^{-\mathrm{S}}$ includes all ETS sectors except for BOF and EAF steel.

2.2. *Disaggregation of the steel sector*

2.2.1. *Production technologies and market shares*

Primary steel is produced via sintering plants (ore concentration)/coking plants, blast furnaces (iron making), and converters (steel production). Secondary steel relies on smelted down scrap and is mostly produced via arc furnace process and to a lesser extent in induction furnaces. The main energy inputs are electricity in the EAF process and coke in the BOF process with EAF steel requiring less than half the primary energy use of BOF steel. Hence, CO_2 emissions are much lower for EAF steel than for BOF steel (ca. 0.4 t versus 1.7–1.8 t of direct CO_2 emissions per ton of crude steel, IEA, 2012). The indirect CO_2 emissions for steel production depend primarily on the carbon intensity of the power mix. In 2013, BOF steel accounted for 71.2% of global crude steel production and EAF steel for 28.2% (World Steel Association, 2014), but shares vary significantly across regions (Table 1). For major steel-producing countries, the share of EAF is over 60% in the USA, Mexico, India, Italy, and Spain, but less than 30% in China, Russia, the Ukraine, Japan, and Australia (World Steel Association, 2014).

2.2.2. *Splitting EAF and BOF steel in GTAP*

To allow for a more realistic modeling of steel production, the GTAP sector ferrous metals (i_s) is disaggregated into BOF steel and EAF steel industries. When splitting the sector using quantity shares of BOF and EAF, we preserved the value of total steel

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[4] Appendix A.1 provides an overview of the production structure together with overview tables of the regions and sectors employed in the model. Appendix A.3 offers sensitivity analyses of the results to the elasticity of substitution between energy and capital, which is a key parameter in CGE-based simulations (Antimiani *et al.*, 2015).

[5] See Table A.2 for the composition of these regions.

Table 1. Overview of global crude steel production in 2013.

Region	Total production of crude steel (in 1,000 t)	Share of global crude steel production	Share of EAF steel
China	716,542	46%	10%
EU 27	168,589	11%	42%
EU 15	143,846	9%	43%
EU 12	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 Association (2014).

production since the GTAP database uses values (not quantities). Thus, prices and quantities are not separately identified. This sector disaggregation mainly affects three parts of the model: inputs used in steel production, export sales, and domestic sales for intermediate use. 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[6]: First, total input costs are allocated to BOF and EAF steel based on the production share of BOF and EAF steel in the Steel Statistical Yearbook for the year 2004 (the base year in the GTAP data). Individual inputs are then allocated to the two processes as follows: coal, other minerals, which include metal ores, refined petroleum and coal products, which include coke, used by the ferrous metals sector are major inputs for the BOF production route and are therefore allocated to the BOF steel industry. Electricity, gas, labor, and capital are major inputs for both production routes. Therefore, we split those production factors between BOF and EAF steel based on estimated cost of each input for BOF and EAF processes in 2011 and the estimated total input cost for BOF and EAF steel production.[7] All remaining intermediate inputs are allocated on a proportional basis to ensure that the estimated total cost for each production process is met.

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[6] See Appendix A.3 for an exemplary calculation of the disaggregation process.

[7] The estimates for the cost shares of BOF and EAF are taken from estimates by Metals Consulting International (MCI) at www.steelonthenet.com.

The export sales of ferrous metal products in the GTAP database are allocated to BOF and EAF steel products using COMTRADE export data. We identified a list of four-digit HS codes that are either primarily associated with BOF steel or EAF steel products.[8] Then, the level of ferrous metal product exports in the GTAP database 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.[9] As a validity check, we compared the outcome with trade data provided by World Steel Association (2014), thereby assuming that flat products are mainly made from BOF steel, whereas long products are mainly made from EAF steel. The trade figures for BOF and EAF based on the World Steel Association (2014) data are quite similar to those resulting from our approach.

The domestic sales of ferrous metal products are disaggregated into sales of BOF and EAF steel products as follows. 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. The sales of ferrous metal products for domestic intermediate use are allocated to BOF and EAF steel products on a proportional basis to ensure that the estimated total sales/cost for each process is obtained. The factor of proportionality is determined by the total sales for each process less the value of exports, sales to private and government households, and own-use intermediate input use.

We also assume that BOF and EAF steel are not substitutable. This approach reflects the (yet) rather limited substitutability of BOF and EAF steel. In practice, BOF steel is typically used for flat products, e.g., in the automobile industry. In contrast, EAF steel is typically used for long products, e.g., for the construction industry. Because of technological progress, the quality of EAF steel is expected to continue to improve, thus increasing substitutability of EAF and BOF steel. Mathiesen and Maestad (2004), for example, employ an elasticity substitution of 0.5. Given the generally small changes in BOF and EAF steel in our analyses, the difference between using an elasticity of substitution of zero or 0.5 is rather negligible. The assumption of zero substitution between BOF and EAF is, however, in contrast to other macroeconomic analyses, for example, Lutz *et al.* (2005) and Schumacher and Sands (2007) which distinguish different steel production technologies in their macroeconomic models but assume crude steel from different production routes to be homogeneous products.

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

[9] Where differences existed between the COMTRADE data for BOF and EAF steel products and the production data from the Steel Statistical Yearbook, the trade shares of BOF and EAF steel were set equal to the production shares of BOF and EAF steel for that region. 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.

3. Scenarios

Our analysis focusses exemplarily on the year 2020. The focus of the paper is, however, on understanding the mechanisms driving the results. We define a basic forecast scenario and two policy scenarios. In the *forecast* scenario, the growth rates in country/region GDP, population, and CO_2 emissions are based on the current policies scenario as defined in the World Energy Outlook 2010 (IEA, 2010). In particular, no additional climate policies are implemented in the *forecast* scenario. World population reaches 7.6 billion in 2020, GDP growth evolves at an average rate of 4% between 2010 and 2020, and CO_2 emissions increase by 16% to 35.2 Gt CO_2 between 2012 and 2020.

3.1. *Description of policy scenarios*

We implement two policy scenarios, which differ by the countries facing emission targets and by the countries and sectors allowed to trade certificates (Table 2). In the *base scenario*, all countries face two emission reduction targets for the period 2012–2020: one for all ETS sectors (i.e., also including steel) and one for non-ETS sectors. There are two four-year time periods in the model: 2013 through 2016 and 2017 through 2020. In the *base scenario*, trading of certificates is only allowed for the ETS sectors within the EU. This scenario serves as a reference to the policy scenario with sectoral targets.

In the *sectoral target* scenario, the ETS emission target is further disaggregated into two targets: one for the steel sector and one for the $\text{ETS}^{-\text{S}}$ sectors. Hence, each country faces three targets (steel, $\text{ETS}^{-\text{S}}$, non-ETS sectors). In this scenario, trading of certificates is allowed between steel industries across all regions. In addition, because the steel sector is part of the EU ETS, trading of certificates is allowed between steel and the other $\text{ETS}^{-\text{S}}$ sectors within the EU 27.

3.2. *Emission targets*

The level of ambition of country targets differs across countries to reflect the principle of "common but differentiated responsibility." 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 (IPCC, 2007; European Commission, 2009). According to Den Elzen *et al.* (2008), non-Annex I countries must reduce their emissions by 15–30% below baseline in 2020 so that the 2°C target may be met. We therefore set the emission targets for all non-Annex I countries to 15% below forecast levels in 2020. Hence, the stringency of climate policy differs across regions in all scenarios. Following the Effort Sharing Decision of the EU (European Commission, 2009), we assume that the ETS sectors account for 60% of the required national emission reductions between 2005 and 2020 in all countries.

Table 2. Policy scenario definitions.

Scenario	Country group	Targets			Trading
		ETS (incl. steel)		Non-ETS	
Base scenario	EU	X		X	Allowed within EU ETS
	Other Annex I	X		X	No trading
	Non-Annex I	X		X	No trading
Sectoral targets scenario		Steel	ETS^{-S}	Non-ETS	
	EU	X	X	X	Allowed for steel sector across regions as well as within EU ETS (steel + ETS^{-S}); no trading for non-steel sectors outside of EU ETS
	Other Annex I	X	X	X	
	Non-Annex I	X	X	X	

Further, we set a sectoral target that requires the steel sector to reduce direct emissions by 10% below forecast in 2020 in all countries.[10, 11] This target is in line with meeting the Best Available Technology for BOF and EAF steel (European Commission, 2012). In the scenarios involving sectoral steel targets, the ETS^{-S} sectors' reduction target is set such that the aggregate target of ETS^{-S} and the steel sector corresponds with the ETS sectors' target in the *base scenario*. Table 3 displays the national emission targets for the policy scenarios together with the emissions in the *forecast* scenario. The targets are in line with model scenarios in the IPCC AR4 report limiting CO_2-equivalent concentrations to low level of about 450 ppm CO_2-eq (likely to limit global warming to 2°C above pre-industrial levels, IPCC, 2014a, b).[12] These targets do not account for emission changes from land use, land-use change and forestry (LULUCF), or from deforestation and degradation (REDD).

All emission reduction targets are applied equally across all time periods in the model, i.e., half the required reduction must be met in period 2013–2016 and the other half in 2017–2020. To meet national, non-ETS, or nonsteel targets, countries employ a domestic price on CO_2 emissions. Trading of credits from CDM or JI projects is not allowed in any scenario.

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[10] Since the majority of the direct CO_2 emissions in the steel sector stems from BOF steel production, the majority of the emission reductions will be achieved by reducing per-unit use of fossil fuel and/or by lowering output.

[11] The 10% reduction below forecast in 2020 in the steel sector is in the same order of magnitude as the reductions realized in the steel sector in the base scenario.

[12] The IPCC AR5 scenarios are based on model inter-comparison projects and individual model exercises leading up to at least 2050. Our 2020 targets are well within their range. Sectoral targets were not explicitly modeled in the exercises included in the IPCC report. The model inter-comparison exercise by the Energy Modelling Forum (EMF 27), for example, included different technology scenarios (for industrial technologies only CCS was explicitly included) and grouped countries/regions to allow for emission trading among some (groups of) countries.

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 certificate price. Table 4 shows the CO_2 certificate prices for the steel sector and the ETS/ETS^{-S} sectors in the different policy scenarios for major steel-producing countries and regions in 2020.[13]

In the *base scenario*, countries face a country-specific uniform certificate price for the steel sector and for ETS^{-S}.[14] The differences in prices between countries reflect differences in the marginal abatement costs, reflecting that the levels of ambition of the emission targets differ significantly. They are most lenient for China and India and most ambitious for Japan and the USA.

In the *sectoral targets* scenario, each country also faces a price for certificates in the steel market, which is identical across all regions because these certificates can be traded globally. Certificate prices for the steel sector are lower than those in the *base scenario* in all countries but China and India. Certificate prices in the ETS^{-S} sector are slightly lower than those in the *base scenario* in all countries, but they are significantly above the certificate prices for the steel sector in all countries but China and India.

Table 3. CO_2 emission targets by region.

	Base year (2012)	Forecast (2020)	Policy scenarios (2020)
	Mt	Mt	Compared to forecast
China	8,084	10,463	−15%
Japan	1,086	1,133	−34%
India	1,745	2,267	−15%
USA	5,455	5,491	−38%
Brazil	424	540	−15%
EU 27	3,728	3,857	−27%
Russia	1,643	1,785	−15%
AI	13,621	14,193	−31%
NAI	16,641	21,029	−15%
World	30,263	35,222	−21%

Source: POLES Forecast.

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[13] Further results, which are not reported here to save space, are available from the authors upon request.

[14] The CO_2 certificate price in the EU 27 in the base scenario is substantially higher than the price currently observed in the EU ETS due to several reasons: The 2020 target implemented is substantially higher than the 2020 GHG reductions targeted at under the EU 20-20-20 policy package. In addition, our scenarios do not allow for using credits from offset projects (e.g. CDM) to reduce mitigation costs. The relatively high CO_2 certificate prices in the *base scenario* in many OECD countries imply that competitiveness and leakage effects are more pronounced than might be expected under known current policy scenarios.

Table 4. CO_2 certificate prices (\$/t CO_2) for steel and ETS/ETS^{-S} sectors in the policy scenarios in 2020.

	Base scenario	Sectoral targets	
	ETS	Steel	ETS^{-S}
China	11		10
Japan	150		166
India	10		11
USA	124	15	128
Brazil	49		57
EU 27	81		84
Russia	38		41

4.2. *Effects of implementing a price for CO_2 emissions for the steel sectors*

Implementing emission targets involves direct and indirect certificate price effects on the production costs for BOF and EAF steel industries. The direct certificate price effect is an increase in input costs for all fossil fuel inputs. The indirect effect is an increase in the price of other intermediate inputs used by the steel sector that are fossil fuel-intensive and are also subject to a certificate price (e.g., electricity or coke). This indirect certificate price effect can be particularly large for EAF steel production in countries in which the power generation relies strongly on fossil fuels.

Several other factors also affect the production of steel: (i) the "own-use effect," (ii) trade effect, (iii) changes in domestic demand, and (iv) a "general equilibrium effect." In the underlying GTAP data, steel is an important input into steel production, accounting for approximately 40% of the cost of all intermediate inputs across all regions. This likely is a reflection of the importance of "unfinished" steel in more refined steel products. Thus, an increase (decrease) in steel prices from higher (lower) fuel input prices is further magnified due to the "own-use" effect.[15]

Because steel is traded intensively, differences in the direct and indirect certificate price effects across countries may affect trade patterns. An extreme example is EAF steel production in Brazil and China. In Brazil, the CO_2 intensity of electricity is close to zero due to the large use of hydropower. Thus, the indirect certificate price effect for Brazilian EAF steel producers is very small. In contrast, given the large use of coal-fired power plants in China, the indirect certificate price effect is much larger. In general, countries in which steel production is less CO_2-intensive (directly and indirectly) enjoy a comparative advantage compared with countries with a high CO_2

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[15] Note that in the GTAP database scrap, which is part of the "recycling" sector (ISIC two-digit number 37), is included with ISIC sector 36 in the GTAP sector manufacturing, n.e.c. In our aggregation, recycling is included in "other manufacturing" (oman).

intensity in steel production. At the same time, countries with a lower certificate price for the power sector enjoy a comparative advantage in EAF steel production compared with countries with higher certificate prices.

Although trade in steel products is important, the majority of steel production is used domestically as intermediate inputs in the manufacturing and service sectors. For example, in our model, approximately one-half of BOF and EAF steel production is used domestically as an intermediate input in other manufacturing. As other manufacturing and services are part of the non-ETS sector and face emission targets in each region, differences in the certificate prices between the non-ETS and ETS sectors within a region and differences in the certificate prices for the non-ETS sector between regions will affect the competitiveness of other manufacturing sectors in each region. Since no substitution is allowed between nonenergy intermediate inputs in the model, a reduction in other manufacturing production will reduce the demand for BOF and EAF steel products.

Finally, the "general equilibrium effects" capture changes in supply and demand in response to price changes. For example, higher certificate 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 certificate prices. This effect is also 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 (e.g., Babiker, 2005). Finally, the implementation of climate change policies will affect the overall demand for capital and labor in each region's economy, thus altering the costs for these factors not only for the steel sectors but for all other sectors as well.[16]

These effects have different orders of magnitude across countries and counterbalance or amplify each other, and their combined impact may increase or offset the direct and indirect certificate price effects. Figures 1 and 2 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.

4.2.1. *Base scenario*

BOF

In the *base scenario*, implementing a certificate price results in a decrease in BOF steel production in most major steel-producing countries compared with the *forecast.* Total world production of BOF steel grows by 1.3% less than the 64.4% increase in BOF production in the forecast simulation without a certificate price. Next, we examine the mechanisms underlying this development for major steel-producing countries.

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[16] 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 certificate prices would induce substitution of BOF steel by EAF steel. As our model assumes a zero elasticity of substitution, this effect is not captured in our analysis.

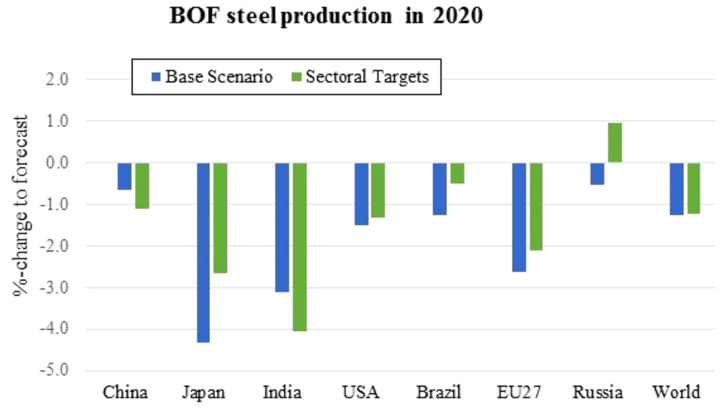

Figure 1. Changes in BOF steel production in 2020 in different policy scenarios compared to the *forecast* (in %).

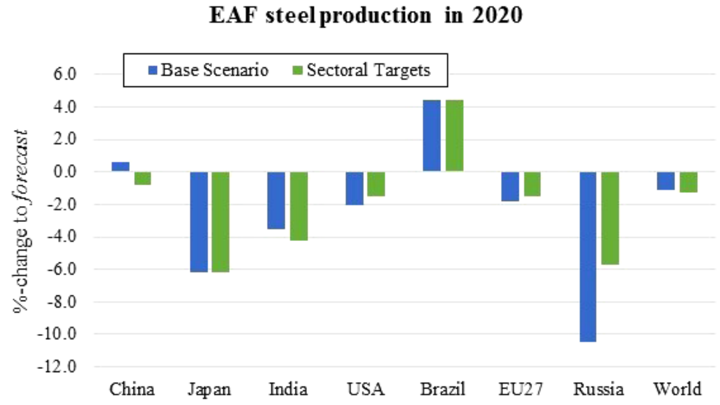

Figure 2. Changes in EAF steel production in 2020 in different policy scenarios compared to the *forecast* (in %).

Most major BOF steel-producing countries do not export a large share of their output. In India, Japan, China, and the USA, over 90% of BOF steel production is used as an intermediate input by domestic firms, mainly in other manufacturing sectors, as own-use by the BOF steel industry and to a lesser extent by the energy-producing sectors. Thus, the decline in BOF steel production is primarily driven by the changes in production in other manufacturing as well as the own-use share of BOF steel.

In contrast, in the EU 27 and Brazil, changes in BOF steel production are driven by trade effects, as both countries are major exporters of BOF steel. In the EU 27, export of BOF steel covers nearly 30% of total production and varies significantly between countries. Approximately 70% of the EU 27 BOF steel exports is intra-EU trade. Hence, relative price changes between EU member states are the driving factors behind changes in exports. Regions with the most energy-intensive steel production, BOF 12, Spain and Italy, experience the largest increases in the price of BOF steel and the largest reductions in exports and BOF production (Table 5).

Similarly, effects on BOF steel production in Brazil can be understood by examining exports. Higher energy prices and significant own-use lead to a more significant increase in the price of Brazilian BOF steel by 2%, compared with global average export price increase of 1%. Therefore, BOF exports decrease. At the same time, we find that an increase in the intermediate use of BOF steel by other manufacturing sectors in Brazil partly offsets this decrease.

EAF

The impact of implementing a certificate price on the EAF steel sector is quite different from for the BOF steel sector for two reasons. First, the indirect effect of certificate prices on the price of electricity is much more important for EAF steel production than for BOF steel production. Secondly, trade effects are much more important for EAF than for BOF steel because globally, about 28% of EAF steel production is exported compared with about 15% of BOF steel production.[17] Although global production of EAF steel decreases by 1.1% in the model compared to the *forecast*, EAF steel production increases in 18 of the 32 regions, in particular in those countries in which the EAF steel industry is not as energy-intensive and/or where the electricity sector is not as CO_2-intensive. Different drivers determine the effects on the country level.

The relatively high energy intensity of EAF steel production in India and Russia helps explain production declines in those countries. The high energy intensity leads to a comparatively high price increase of EAF steel in India and Russia (by 3.6% and 6.2%, respectively, compared to the global average increase of 3.1%, see Table 5). Thus, EAF steel exports decrease for both countries, with a much larger decrease for Russia given the much larger relative price increase. In contrast, price increases for EAF steel in the UK and REU 15 are lower than the average because these countries have relatively energy-efficient EAF steel production.

The USA and Japan also experience relatively large price increases for EAF steel, 4.5% and 4.9%, respectively, leading to a decline in EAF exports in those two countries. However, while in the USA and Japan, EAF steel is relatively energy-efficient, both regions see larger increases in the price of electricity than the global average: 33.2% for the USA and 13.6% for Japan compared with the average global increase of 13.5%. The large increase in the USA electricity price is due to a higher ETS certificate price as well as the USA electricity sector being relatively more reliant on coal than other regions in the model.

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[17] Trade intensity figures are driven by China, which is by far the largest producer of BOF steel, but uses almost all BOF steel domestically. Without the figures for China, BOF steel is — as expected — more trade-intensive than EAF steel, because BOF steel is of higher quality.

Table 5. Changes in BOF and EAF steel price and output in the *base scenario* compared with the *forecast* (in %).

	BOF				EAF					
	Intermediate use	Exports	Output	BOF price	Energy share EAF	Electricity price	EAF price	Intermediate input	Exports	Output
Region										
China	−0.7	5.0	−0.6	0.1	0.12	10.7	2.4	0.1	2.4	0.6
Japan	−3.1	−16.0	−4.3	4.1	0.15	13.6	4.9	−5.0	−9.5	−6.2
India	−3.1	−4.1	−3.1	1.5	0.14	6.6	3.6	−3.4	−4.1	−3.5
USA	−1.5	−0.8	−1.5	2.0	0.10	33.2	4.5	−1.9	−3.4	−2.0
Brazil	−0.6	−5.3	−1.3	2.0	0.25	0.3	1.2	2.6	8.9	4.5
Russia	−2.0	0.5	−0.5	0.9	0.37	14.4	6.2	−7.7	−3.9	−10.5
World			−1.3	1.0			3.1			−1.1
France	−0.6	0.5	−0.4	1.2	0.07	3.3	1.8	3.2	5.8	4.5
Germany	−1.3	−2.6	−1.5	1.9	0.15	12.7	4.0	−4.8	−4.3	−4.4
Italy	−3.2	−10.6	−3.9	3.3	0.19	11.2	4.7	−5.2	−8.1	−6.9
Spain	−3.4	−6.5	−4.2	2.4	0.10	14.0	3.1	−1.8	−0.8	−1.6
UK	0.6	2.5	1.1	0.7	0.09	13.8	2.5	0.8	3.6	1.6
BOF 15	0.5	1.1	0.8	1.1	0.11	5.8	2.7	0.7	1.4	1.1
REU 15	−2.9	−3.3	−3.1	1.8	0.07	13.7	2.2	1.1	4.1	2.5
BOF 12	−7.7	−19.8	−12.3	5.9	0.26	20.5	8.5	−11.8	−22.8	−15.8
REU 12	−2.6	−1.1	−2.3	1.3	0.05	18.1	2.9	−2.5	0.1	−2.0

Low carbon intensity in electricity generation is driving results in Brazil, France, and the BOF 15. The use of hydropower (Brazil), nuclear (France), and natural gas (BOF 15) results in a lower increase of the electricity price in those countries. Therefore, EAF exports grow in these regions.

For China, we find an increase in EAF steel exports despite electricity production being relatively coal-intensive. The lower ETS certificate price in China limits the increase in the price of electricity to 10.7%, which is a smaller increase than in other major EAF-producing regions.

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. With certificates for the steel sector traded globally, there is a single certificate price for all steel producers. In contrast, in the *base scenario*, the certificate price faced by steel producers varied across regions. As shown in Table 4, the certificate prices for steel producers are lower in this scenario compared with the *base scenario*, except for China and India. The overall change in global BOF and EAF steel production in this scenario is similar to *base scenario*. However, as we will discuss next, there are significant changes in the

Table 6. Changes in BOF and EAF steel price and output in the *sectoral targets scenario* compared with the *forecast* (in %).

	BOF				EAF				
	Intermediate use	Exports	Output	BOF price	Electricity price	EAF price	Intermediate input	Exports	Output
Region									
China	−1.1	−1.4	−1.1	0.5	10.4	2.3	−0.8	−0.8	−0.8
Japan	−2.1	−7.7	−2.7	1.7	14.6	4.3	−4.9	−9.5	−6.2
India	−3.7	−9.8	−4.1	2.1	6.4	3.5	−3.9	−7.1	−4.2
USA	−1.3	−1.5	−1.3	0.6	33.9	2.7	−1.6	−0.9	−1.5
Brazil	−0.2	−2.5	−0.5	0.7	0.3	0.4	2.6	8.7	4.4
Russia	−1.0	2.3	0.9	−0.2	15.1	3.8	−4.9	−6.6	−5.7
World			−1.2	0.7		2.5			−12
France	−0.8	−1.2	−0.9	0.7	3.3	1.3	2.2	4.3	3.3
Germany	−1.5	−3.6	−1.8	1.2	13.1	3.0	−3.8	−3.4	−3.5
Italy	−2.2	−5.9	−2.6	1.5	11.7	3.6	−4.2	−6.6	−5.6
Spain	−1.0	1.3	−0.4	0.3	14.4	2.3	−1.7	−1.0	−1.5
UK	0.3	0.3	0.3	0.3	14.2	1.8	0.8	2.9	1.4
BOF 15	0.2	0.0	0.1	0.5	5.9	1.7	1.7	2.6	2.2
REU 15	−3.0	−3.4	−3.2	1.1	14.1	1.4	1.0	3.9	2.4
BOF 12	−5.3	−13.3	−8.4	3.4	21.0	6.8	−10.1	−19.6	−13.6
REU 12	−2.5	−1.9	−2.4	0.6	18.5	2.3	−2.6	−0.9	−2.2

composition of global steel production across regions (Table 6). Most of the effects can be ascribed to the changes in CO_2 prices experienced at the country level.

BOF

Because of the higher certificate prices in China and India, the price of BOF steel produced in China and India increases by about 0.4% and 0.6% points more than in the *base scenario*. In contrast, the increase in the world export price compared to the forecast is lower than that in the base scenario. Thus, producers in both regions lose export competitiveness in this scenario. The loss of exports, which is amplified by significant own-use, results in 0.5% and 1.0% point larger decreases in BOF steel production in China and India compared with the *base scenario*.

In the other major BOF steel-producing regions, the certificate price is substantially lower compared with the *base scenario*. In Brazil and Japan, this reduces the negative effects on export competitiveness found in the base scenario. Reductions in BOF steel production are lower than those in the base scenario. A similar, but more pronounced effect can be found in Russia, where the change in certificate prices is significant. It falls from \$38/t to \$15/t, compared to the *base scenario*. In combination with lower energy prices due to lower global demand for fossil fuels, the price of Russian BOF steel now decreases slightly even below the *forecast*. That enhances Russia's export competitiveness and results in an overall increase in Russian BOF steel production compared also with the *forecast*.

Also for the EU 27, the certificate prices for BOF steel producers are lower compared with the *base scenario*, leading to smaller price increases. Effects on aggregate BOF steel production are minor and result in a slightly higher production compared with the base scenario, yet still negative compared with the forecast. As a uniform ETS price is applied in the EU 27 in both scenarios, the base scenario and the sectoral targets scenario, effects in the EU 27 are determined by the energy intensity of the production process in the individual countries and regions. Accordingly, countries with the highest energy intensity in production benefit the most: Italy, Spain, and BOF 12. For the other EU 27 regions with less energy-intensive BOF production, smaller price changes relative to the energy-intensive regions imply either a smaller gain or a larger reduction in exports, e.g., gains in BOF exports and production in the UK and the BOF 15 drop significantly.

EAF

EAF steel production has lower direct CO_2 emissions than BOF steel production; yet the relative changes in certificate prices still have significant effects on EAF steel production across regions. Lower certificate prices faced by most steel producers in this scenario lead to lower input costs and price increases. The aggregate world price of EAF steel increases by only 2.5%, compared with a 3.1% increase in the *base scenario*.

As seen for BOF steel, China and India are two exceptions, in which the certificate price is higher in this scenario than in the *base scenario* ($15/t versus $11/t). However, the price for electricity in both regions is lower compared with the base scenario due to the certificate price for the ETS^{-S} sectors in both regions decreasing slightly. The lower electricity price offsets the higher certificate price, resulting in similar price increases for EAF steel in China and India as in the *base scenario*. However, as the world price of EAF steel increases by 0.6% points less than in the *base scenario*, Chinese and Indian EAF steel producers lose competitiveness. EAF exports from China and India both decline by 3.2% and 3.0% points, respectively, compared with the *base scenario*. In addition, Chinese EAF exports and production switch from increasing in the *base scenario* to decreasing in this scenario.

In other major EAF-producing regions, the relatively large reduction in the certificate prices leads to smaller price increases. In Russia, the USA, Brazil, and Japan, the price increases are lower than those in the *base scenario*. As the aggregate global price of EAF steel decreases less than EAF prices in these regions, they either experience lower reductions in exports (Russia, USA, and Japan) or an increase in exports (Brazil). Hence, the introduction of sectoral targets leads to a lower reduction in EAF steel production in Russia, the USA, and Japan and to an increase in EAF steel production in Brazil.

In the EU 27 regions — as in the case of BOF steel — the impact of introducing steel sector targets is the greatest for the regions with the most energy-intensive EAF

Table 7. CO_2 emissions and certificate trading (Mt) in the steel sector in 2020.

	CO_2 emissions in the steel sector		Certificate sales (−) and purchases (+)
	Base scenario	Sectoral targets	
China	546	518	−5
Japan	30	36	−1
India	91	88	−3
USA	35	43	−3
Brazil	26	27	1
EU 27	63	71	1
Russia	66	71	4

production (Germany, Italy, the BOF 15, and the BOF 12). They benefit the most from the lower certificate price compared with the base scenario. Total EAF steel production in the EU 27 declines by 1.5% in this scenario compared with 1.8% in the *base scenario*.

Certificate trading

Table 7 shows the amount of certificates traded on the steel market in the *sectoral targets* scenario. Overall, trade of CO_2 certificates is minor. Major sellers are China and India, which have a large reduction potential in BOF steel production, as well as the USA. The sale of 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. The sectoral targets allow Russia to increase BOF production by purchasing certificates from the steel sectors abroad.

4.2.3. *Measuring changes in competitiveness effects of sectoral approaches*

To capture the extent to which sectoral approaches are able to countervail the negative effects of country differences in the stringency of climate policy on steel market output, we calculate the changes in a country's global output shares for the three policy scenarios compared with the *forecast* in 2020 for both BOF and EAF (Table 8).

BOF

For BOF steel production, China, India, and Russia gain market share between 2012 and 2020 in the *forecast*. Until 2020, China increases its market share by 12%, covering about 49% of global BOF steel production. India and Russia increase their share by 1%, accounting for about 5% and 6% of global production, respectively. The largest declines in market share occur in the USA and the EU 27, who both lose around 2% covering about 5% and 14% of global production in 2020.

In the *base* scenario, China gains slightly more market share in 2020, compared with the forecast market share, whereas Japan and the EU 27 lose additional market share to a small extent. Interestingly, India loses market share compared with the

Table 8. Effects of policies on market shares of BOF and EAF.

	BOF				EAF			
	Change in market share in forecast between 2012 and 2020 (in %)	Market share (in %) forecast in 2020	Difference in market shares in the policy scenarios compared to *forecast* in 2020		Change in market share in forecast between 2012 and 2020 (in %)	Market share (in %) forecast in 2020	Difference in market shares in the policy scenarios compared to *forecast* in 2020	
			Base scenario	*Sectoral targets*			*Base scenario*	*Sectoral targets*
China	12.03	48.93	0.17	0.12	9.70	22.99	0.43	0.18
Japan	−4.40	8.68	−0.17	−0.10	−2.87	7.00	−0.32	−0.31
India	1.50	4.71	−0.08	−0.10	3.37	8.39	−0.20	−0.24
USA	−2.04	4.91	0.00	−0.02	−3.18	12.09	−0.08	−0.04
Brazil	−0.60	1.59	0.01	0.01	−0.41	0.95	0.04	0.04
EU 27	−5.32	13.62	−0.14	−0.13	−3.75	17.53	−0.13	−0.07
Russia	1.26	5.87	0.02	0.10	0.20	1.66	−0.13	−0.06

forecast. Most other differences in market share between the *forecast* and the *base scenario* are small. Introducing sectoral targets reduces the extent of the changes in market share in the *base scenario* for most countries. This is not true for Russia, who can further increase its market share compared with the base scenario as well as for India and the USA, who lose slightly more market share in the *sectoral targets* scenario.

For the countries with the highest certificate prices in the *base scenario*, i.e., Japan, USA, and EU 27, the *base scenario* results in a combined global BOF market share loss of 0.0031. In *sectoral targets*, this loss amounts to 0.0025. Hence, for these countries, *sectoral targets* makes up for about 20% of the loss in global BOF market share in the *base scenario*.

EAF

For EAF steel production, again China has the largest market share in 2020 with an increase of 10% between 2012 and 2020. In addition, India experiences increases in market share between 2012 and 2020 in the *forecast*, whereas Japan, the USA, and to a lesser extent also the EU 27 face the largest decreases. The impacts of the policy scenarios for China and India are the same as they were for BOF steel. China increases market share in 2020, compared with the *forecast*, in the *base* and *sectoral targets* scenarios. India loses market share across both policy scenarios, compared with the forecast. Qualitatively, for Japan, the USA, Brazil, and the EU 27, the policy scenarios have the same impacts for EAF as for BOF steel.

For the countries with the highest certificate prices in the *base scenario*, i.e., Japan, USA, and EU 27, the combined global EAF market share loss in the *base scenario* is 0.0053, and 0.0042 in *sectoral targets*. Thus, *sectoral targets* makes up for about 20% of the loss in global EAF market share in the *base scenario*.

5. Conclusions and Policy Implications

Relying on a multi-country, multi-sector recursive dynamic CGE model, we focus on the competitiveness effects of sectoral targets for the steel sector in international climate policy and their interaction with ETS. To better reflect technological realities and to account for different energy and carbon intensities of production, the 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.

Our policy simulations suggest that sectoral targets may effectively counter the (negative) output effects of differences in the stringency of climate policy across countries. The findings differ, however, by country and steel production technology. In comparison to the *base scenario*, allowing for global trading on the steel market in the *sectoral targets* scenario improves the competitiveness of steel production in Annex I countries with stringent targets and relatively high marginal mitigation costs. For these countries, certificate prices for steel are lower in the *sectoral targets* scenario so that production costs are lower, export competitiveness improves, and output is higher than that in the *base scenario*.

In comparison to other countries, India and China are negatively affected by sectoral targets because of direct and indirect cost effects. Higher certificate prices both for the steel and the $\mathrm{ETS}^{-\mathrm{S}}$ sectors compared with the *base scenario* result in a loss of export competitiveness and decreased production in both countries.

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 compared with the *base scenario*. The effect on global EAF production is negative in the *sectoral targets* scenarios. In the *sectoral targets* scenario, BOF accounts for about 90% of the emission reductions in the steel sector.

The results of the policy simulations further suggest that splitting the steel sector into its major processes allows for additional insights into inter-industry effects. For most countries, the relative magnitude of the output effects for BOF and EAF differs noticeably in all policy simulations. Moreover, the outputs' effect of BOF and EAF tends to be of opposite directions.

Last but not the least, our policy simulations suggest that sectoral targets may effectively counter the (negative) effects of climate policy involving differences in stringency across countries on global steel market shares, in particular for EAF. For the countries with the highest certificate prices in the *base scenario*, i.e., Japan, USA, and EU 27, a *sectoral targets* approach would reduce about 20% of the loss in their global BOF and EAF market shares in the *base scenario*.

Appendix A

A.1. *Production structure in GTAP-E*

In the GTAP-E production structure (Fig. A.1), firms cannot substitute among nonenergy intermediate inputs or between nonenergy intermediates and a primary factor composite. The primary factor composite includes land, skilled and 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 three inter-fuel substitution possibilities: (a) electricity and the nonelectricity composite; (b) coal and the noncoal composite; and (c) between oil, gas, and petroleum products. A key model parameter is the elasticity of substitution between capital and the energy composite, σ_{KE}, which we set equal to 1.0. At this level, capital and energy are substitutes in all industries.[18] Appendix A.3 provides results of sensitivity analyses with respect to σ_{KE}.

As is standard in multi-county CGE models (e.g., Capros *et al.*, 2013), demand for each final and intermediate good is split optimally between domestically produced and

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[18] 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.

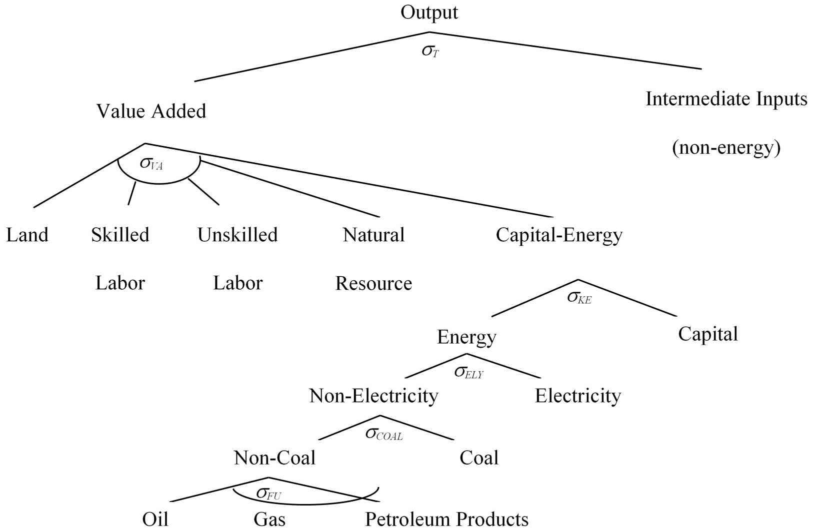

Figure A.1. Model structure.

imported goods, following the "Armington" assumption. That is, domestic and imported goods are considered to be imperfect substitutes.

The periods are linked via investment decisions of the representative regional household, who holds a mix of domestic and "foreign" financial assets, backed by the physical capital owned by domestic or foreign firms. Households invest their savings using a lagged adjustment, adaptive expectations theory of investment in which any disparities in expected rates of return across regions are not eliminated instantaneously, but progressively through time by reallocation of capital from regions with lower

Table A.1. Overview of countries and regions.

Australia	BOF 15 (Austria, Belgium, The Netherlands, Sweden)
China	REU 15 (Denmark, Finland, Greece, Ireland, Luxembourg, Portugal)
Japan	BOF 12 (Czech Republic, Hungary, Poland, Romania, Slovakia)
South Korea	REU 12 (Bulgaria, Cyprus, Estonia, Latvia, Lithuania, Malta, Slovenia)
Indonesia	Switzerland
India	Norway
Canada	Russia
USA	Ukraine
Mexico	Turkey
Argentina	Egypt
Brazil	South Africa
France	Rest of Annex I
Germany	Rest of non-Annex I developed countries
Italy	Rest of advanced developing countries
Spain	Rest of other developing countries
Great Britain	Rest of least developed countries

Table A.2. Overview of sectors.

Agriculture (agr)	Chemicals, rubber, and plastics (crp)
Coal (coa)	Nonmetallic minerals (nmm)
Oil (oil)	Primary steel (bof)
Gas (gasd)	Secondary steel (eaf)
Other natural resources (othnat)	Nonferrous metals (nfm)
Food (food)	Electricity (ely)
Other manufacturing sectors (oman)	Services (serv)
Pulp and paper (ppp)	Wholesale/retail trade (trd)
Refined petroleum and coal products (p_c)	Transport margins (trans)

expected rates of return to regions with higher expected rates of return (Ianchovichina and Walmsley, 2012).

A.2. *Exemplary disaggregation of input costs of the steel sector*

The following table shows the calculation of the disaggregation of the steel sector into BOF and EAF steel exemplarily for Australia.

A.3. *Sensitivity of results to elasticity of substitution between energy and capital*

In assessing the impact of emission reductions on economic activity, one key model parameter is the elasticity of substitution between energy and capital, σ_{KE}. The easier it is for industries to substitution away from energy inputs as their relative prices increase due to climate policies, the smaller the impact will be of those climate policies. However, empirical estimates of σ_{KE} are available only for broadly defined sectors and with limited evidence on how they may vary across countries (Antimiani *et al.*, 2015).

In our base set of parameters, we assume a larger value of σ_{KE} equal to 1.0, twice the standard values in the GTAP database because we utilize 4-year time periods in our

Table A.3. Disaggregation of input costs of the steel sector in Australia.

	Unit	Total	BOF	EAF
Share in total production	Percent	100	80.1	19.9
Total input costs	Million US $	12,684.6	10,161.0	2,523.6
Raw materials				
Coal	Million US $	3.9	3.9	0.0
Other minerals	Million US $	1,124.6	1,124.6	0.0
Refined petroleum and coal products	Million US $	248.9	248.9	0.0
Electricity	Million US $	489.6	284.0	205.6
Natural gas, labor, capital	Million US $	4,359.7	3,837.3	522.4
Total	Million US $	6,226.8	5,498.7	728.0
Remaining intermediate inputs (share)	Million US $ (Percent)	6,457.8	4,662.3 (72%)	1,795.5 (18%)

simulations, with a longer time horizon implying greater substitution possibilities. In this section, we will consider two alternative values for σ_{KE}: a value of 0.5 across all sectors and regions and a set of values that do vary across sectors, but not regions, from Case C in Antimiani *et al.* (2015). These latter values of σ_{KE} range from 0.13 for wood products to 0.45 for food, with a value of 0.24 for basic metals.

As shown in Table A.4, reductions in the value of σ_{KE} can have substantial impacts on the certificate prices of CO_2 in the ETS sector, similar to the findings of Antimiani *et al.* (2015). For regions such as China and India, which are relatively more energy-intensive and have lower emission targets, the absolute increase in the certificate price is much smaller, reflecting a lower marginal cost of abatement. For regions such as the USA and Japan with larger emission targets and are relatively less energy-intensive, the marginal cost of abatement becomes much higher with a lower value of σ_{KE}. Across the different scenarios, as the values of σ_{KE} decrease, the levels of the certificate prices increase. Although not shown in Table A.4, reductions in σ_{KE} have much smaller impacts on the certificate prices in the non-ETS sector in all regions.

Because steel is used mainly as an intermediate input, global production is closely tied to changes in global economic activity. Higher certificate prices in the ETS sectors, due to lower values of σ_{KE}, should have an adverse impact on global GDP and therefore on global steel production. In the base and sector targets scenarios, using our base parameters, global GDP decreases by 0.9% compared with the forecast level of global GDP in 2020 or approximately \$660 billion. Decreasing the value of σ_{KE} by one-half would cause a 0.2% point decrease in global GDP (from -0.9% to -1.1%) or an additional \$140 billion reduction. Using the still lower values in Case C results in an additional 0.1% point decrease (to -1.2%), or \$60 billion, in global GDP. As shown in Table A.5, these relatively small reductions in GDP result in slightly larger decreases in steel production, with the larger reductions occurring for BOF steel. The higher certificate prices also lead to larger price increases, compared with the base model parameters.

Table A.4. Certificate prices (\$/t CO_2) for ETS sector in 2020.

	Base scenario			Sectoral targets		
Region	Base σ_{KE}	0.5 σ_{KE}	Case C[a]	Base σ_{KE}	0.5 σ_{KE}	Case C[a]
China	10.55	17.24	21.01	10.40	17.21	20.97
Japan	150.37	300.92	400.49	165.50	342.32	455.84
India	10.47	16.94	20.41	10.59	16.97	20.42
USA	124.12	235.57	294.86	127.58	245.49	307.59
Brazil	49.38	79.26	96.67	57.16	94.76	115.60
EU 27	81.09	147.23	181.04	83.69	154.13	186.56
Russia	38.45	54.31	61.08	40.66	55.03	61.27
Steel				14.93	15.41	21.50

[a] Case C utilizes the values of σ_{KE} in Table 1 in Antimiani *et al.* (2015).

Table A.5. Changes in global steel production and prices under alternative parameter values.

	Global steel production		Global steel prices	
Scenario	BOF	EAF	BOF	EAF
Base				
Base σ_{KE}	−1.28	−1.13	1.04	3.14
0.5 σ_{KE}	−1.58	−1.10	2.53	5.49
Case C[a]	−1.76	−1.13	3.43	6.77
Sectoral targets				
Base σ_{KE}	−1.25	−1.24	0.70	2.49
0.5 σ_{KE}	−1.51	−1.32	1.25	4.30
Case C[a]	−1.67	−1.38	1.95	5.40

[a] Case C utilizes the values of σ_{KE} in Table 1 in Antimiani *et al.* (2015).

Table A.6 shows how changes in the values of σ_{KE} affect the changes in BOF and EAF production across regions. For the most regions, the value of σ_{KE} does not affect the direction of the change in production, although the magnitudes do vary somewhat. There are three exceptions to this general observation. First, in the base scenario, the change BOF steel production in Russia compared with the forecast changes sign from a reduction when using the base parameters, to a small increase when using smaller

Table A.6. Changes in steel production by region from changes in parameter values.

	Base scenario			Sectoral targets		
Region	Base σ_{KE}	0.5 σ_{KE}	Case C[a]	Base σ_{KE}	0.5 σ_{KE}	Case C[a]
BOF						
China	−0.6	−0.9	−1.1	−1.1	−1.6	−1.6
Japan	−4.3	−5.5	−6.0	−2.7	−2.4	−1.9
India	−3.1	−3.2	−3.1	−4.1	−4.4	−3.6
USA	−1.5	−0.7	−0.2	−1.3	−0.6	0.2
Brazil	−1.3	−2.2	−2.8	−0.5	−0.9	−1.8
EU 27	−2.6	−3.4	−3.8	−2.1	−3.2	−3.4
Russia	−0.5	0.3	0.5	0.9	1.4	1.6
EAF						
China	0.6	2.1	2.9	−0.8	−0.5	0.3
Japan	−6.2	−10.0	−11.8	−6.2	−10.2	−11.1
India	−3.5	−3.1	−2.9	−4.2	−4.4	−3.6
USA	−2.0	−1.6	−1.1	−1.5	−0.7	0.2
Brazil	4.5	5.5	5.6	4.4	5.1	3.2
EU 27	−1.8	−2.7	−3.1	−1.5	−2.3	−2.5
Russia	−10.5	−12.7	−13.6	−5.7	−6.0	−4.0

[a] Case C utilizes the values of σ_{KE} in Table 1 in Antimiani *et al.* (2015).

values of σ_{KE}. This occurs because certificate prices in Russia increase relatively less (on a percentage basis) than other steel-producing regions, leading to larger exports of BOF steel from Russia. Secondly, USA production of BOF and EAF steel in the sector targets scenario changes from a decrease relative to the forecast when using the base parameters to a small increase relative to the forecast when using the parameters in Case C. This occurs because of significantly larger increases in BOF and EAF steel exports to Canada. The growth in the demand for steel in Canada is large enough; even with the purchases of steel emission certificates, steel imports to Canada must increase to meet its demand. The USA is the largest exporter of both BOF and EAF steel to Canada. Finally, change in EAF steel production in China switches from a reduction relative to the forecast to an increase relative to the forecast in Case C of the sector targets scenario. A smaller σ_{KE} leads to larger electricity price increases in many regions. However, the price increase is smaller for China because of the lower emission targets. As electricity is a key input in the production of EAF steel, a relatively smaller increase in the price of electricity improves China's competitive position, leading to higher exports.

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