Sectoral Targets as a Means to Reduce Global Carbon Emissions

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Everett B. Peterson[a],

Joachim Schleich[a b c],

and Vicki Duscha[b]

Abstract:

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[a] Department of Agricultural and Applied Economics, Virginia Polytechnic Institute & State University, 202A Hutcheson Hall, Blacksburg, VA 24061, USA

[b] Fraunhofer Institute for Systems and Innovation Research

[c] Grenoble Ecole de Management, 12, rue Pierre Sémard - BP 127 - 38003 Grenoble Cedex 01, France

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 legally binding agreement on climate change no later than 2015 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 perceive will slow their development. Conversely, some industrialized countries are reluctant to unilaterally commit to emission reductions if other countries they compete with in international markets do not face similar emission restrictions.

On the other hand, because the top-down approach of 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 membership, 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, or Bodansky 2003) or joint binding agreements between sectors and governments of countries (sectoral approaches) may be a means to entice major developing countries to participate (e.g. Baron et al. 2008, 2009; Fujiwara 2010a, b, The Center for Clean Air Policy 2010). Sectoral targets could allow for efficiency gains while at the same time address the concerns of competitiveness and carbon leakage of industrialized countries. Sectoral approaches may involve linking of multi-sector emissions trading systems (ETS) such as the existing EU ETS (e.g. Ellerman et al. 2010) across countries and regions (e.g. Anger 2008; Jaffe et al. 2009; Flachsland et al. 2009; Tuerk et al. 2009) or transnational approaches for individual energy-intensive sectors, as proposed for the cement, steel or electricity sectors, or land transportation (WBCSD 2009; Binsted 2010; Wooders 2010; Meunier and Ponssard 2011; Voigt et al. 2011, Gavard et al. 2011).

Previous research of sectoral approaches mainly involve 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 2011). In this paper, we explore the role of sector emission targets in future international climate agreements in a macroeconomic framework, their interaction with existing/planned ETS, and whether sector targets can address the concerns of carbon leakage and loss of competitiveness for the steel sector. 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. Second, the steel industries is trade intensive with approximately 20% of the value of steel output traded (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, we disaggregate the steel sector into two industries by production process in each region.

To explore the implications of sectoral targets, we investigate three alternative scenarios. In the first scenario, regions achieve a given emission target via a single domestic emission market, which yields a single tax on CO_2 emissions. In the second scenario, the single domestic emission market is disaggregated into three markets: one for the steel sector, one for all other energy-intensive industries (ETS), and one for all other industries and private/government consumption. Emission trading is not allowed between these three emission markets or between regions. In the last scenario, the steel and ETS emission markets are "linked" such that the CO_2 tax for the steel sector cannot be higher than the CO_2 tax for the ETS sector, but can be lower. International emission trading is not allowed in all scenarios. For each scenario, we assume that all regions must reduce their CO_2 emissions in 2020 by 20% compared to their forecasted level of emissions in 2020. We also assume that regions will achieve half of the required emission reductions in the 2013-2016 period and the remaining half in the 2017-2020 period.

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[1] For example, in 2010 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 for less than 10% of total crude steel production (World Steel, Statistical Yearbook 2011)

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. Sections 4 and 5 provide the specific emission targets in each scenario and present the model results. The final section discusses the findings and concludes.

2 Empirical Model

The multi-country, multi-sector, recursive dynamic computable general equilibrium (CGE) model (DYE-CLIP), developed by Peterson et al. (2011), is used in this analysis.. 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, and gas) as intermediate inputs is governed by a nested Constant Elasticity of Substitution (CES) production function as used in the GTAP-E model (Burniaux and Truong, 2002). Firms cannot substitute among non-energy intermediate inputs or between non-energy intermediates and a primary factor composite. The primary factor composite is composed

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[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%.

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.[4]

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 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

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[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 Werft, for example, suggest that energy and capital are substitutes.

parameter values are set to the base values in the GTAP 7 database. T he 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 including Australia, China, Japan, South Korea, India, Canada, the United States, Mexico, Argentina, Brazil, France, Germany, Italy, Spain, the United Kingdom, Norway, Russia, Ukraine, and South Africa. There are four aggregate regions for the EU that identify the main BOF steel producers in the EU15 and newly ascended members not individually identified (BOF15 and BOF12) and all other EU15 and new ascended members (REU15 and REU12). The model has 18 sectors, including electricity (ely), refined petroleum and coal (p_c), chemicals, rubber and plastics products (crp), other mineral products (nmm), paper products (ppp), and non-ferrous metals (nfm). The GTAP sector ferrous metals (i_s) is disaggregated into BOF steel and EAF steel industries.

3 The steel sector

3.1 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.[4] 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 compared with 1.7-1.8 mt of CO_2 per mt of crude BOF steel (IEA, 2012).

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 2011). As can be seen from Table 1, the shares of BOF and EAF steel differ significantly across countries and regions.

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[4] An in depth description of the production processes in the iron and steel sector can be found in the recent report by the European Commission’s Joint Research Centre .

Taking into account indirect CO_2 emissions as well, the CO_2 emissions of the steel sector in a particular country not only depend on technological efficiency and the structure of steel production, 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.

Despite these differences in production processes, most top-down type modelling analyses treat steel production as homogenous. Notable exceptions include Lutz et al. (2005) for a macro-econometric model and Schumacher and Sands (2007) for a CGE model. They both distinguish between BOF and EAF processes for a single country, i.e. Germany.

3.2 Disaggregation of the steel sector

The GTAP sector ferrous metals (i_s) is disaggregated into two industries based on production data for the Steel Statistical Yearbook (Worldsteel 2011) 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[5] 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

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[5] Total input cost is defined as sum of VDFA plus VIFA across all intermediate inputs plus EVFA for all primary factors used by ferrous metals in the GTAP database.

production in Australia in the GTAP database, \$12,684.6 million, 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 2 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 cost 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 process 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:

$$VFA_{ely,EAF} = \frac{VFA_{ely,i\_s}}{\left(1 + \frac{c_{ely,BOF}}{c_{ely,EAF}} \frac{TC_{BOF}}{TC_{EAF}}\right)} \tag{1}$$

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 ferrious 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. Again, using Australia as 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. Equation (1) 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 equation (1) that uses the relative labor cost shares instead of the electricty cost shares. Finally, capital is allocated with a a variant of equation (1) 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

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.[6] 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.[7] 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 is 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

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[6] 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.

[7] 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.

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.[8] Finally, the sale of ferrous metal products for domestic intermediate use, other than own-use, is allocated using the BOF intermediate product sales share.

4 Emission Forecasts

As noted above, in all scenarios, all regions must reduce their CO_2 emissions by 20% compared to their forecasted level of emissions in 2020. Table 3 lists the forecast level of emissions for each region for the four year periods 2013-2016 and 2017-2020. All regions must reduce their forecast CO_2 emissions by 10% by the end of the 2013-2016 period and by 20% by the end of the 2017-2020 period. 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 is not allowed in any scenario.

5 Results

Table 4and Table 5 present the change in output in the steel industry by production process across the three policy scenarios.

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

Still to be completed.

6 Conclusions

Still to be completed.

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References

Baron, R., I. Barnsley, and J. Ellis (2008), Options for integrating sectoral approaches into the UNFCCC.

Baron, R., B. Buchner, and J. Ellis (2009), Sectoral Approaches and the Carbon Market. IEA/OECD paper for the Annex I Expert Group on the UNFCCC, OECD/IEA, Paris.

Binsted, A., Dalkmann, H., Bongardt, d., Sakamoto, K. (2010): .Reducing Emissions through Sustainable Transport (REST) Proposal for a sectoral approach as a means to increase the potential for GHG mitigation in the land transport sectors of both developed and developing countries. Final Draft - 23 August 2010"Bridging the Gap: Pathways for Transport in a Post 2012 process" (www.transport2012.org)

Burniaux, J.-M. and P. Truong. (2002). GTAP-E: An Energy-Environmental Version of the GTAP Model. GTAP Technical Paper No. 16 (Revised.

Ianchovichina, E. and R. McDougall (2001). Theoretical Structure of Dynamic GTAP. GTAP Technical Paper No. 17, Global Trade Analysis Project, Department of Agricultural Economics, Purdue University, West Lafayette.

Center for Clean Air Policy (2010), Global Sectoral Study: Final Report, May.

Ellerman, A.D., F.Convery and C.de Perthuis (2010).Pricing Carbon: The European Union Emissions Trading Scheme, Cambridge: Cambridge University Press.

Flachsland, C., R. Marschinski, and O. Edenhofer (2009), "Global Trading versus Linking: Architectures for International Emissions Trading," Energy Policy 37, 1637-1647.

Gavard, C., Winchester N., Henry Jacoby, H., S Paltsev (2011), What to Expect from Sectoral Trading: A U.S.-China Example. MIT Joint Program on the Science and

Policy of Global Change, Report No. 193. February.

Fujiwara N. (2010a), The merit of sectoral approaches in transitioning towards a global carbon market. Center for European Policy Studies, Special Report.

Fujiwara N. (2010b), Sectoral Approaches to Climate Change. What can industry contribute? Center for European Policy Studies, Special Report.

IEA, 2012: Profiles: CO_2 abatement in the iron and steel industry. IEA Clean Coal Center, February 2012.

Jaffe, J., Ranson, M., Stavins, r.N: (2009): Linking Tradable Permit Systems: A Key Element of Emerging International Climate Policy Architecture. Ecoology Law Quarterly 36, 789-808.

Joint Research Centre – Institute for Prospective Technological Studies (2012): Best Available Techniques (BAT) Reference Document for Iron and Steel Production, Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control). European Integrated Pollution Prevention and Control Bureau (EIPPCB) at the European Commission's Joint research Centre - Institute for Prospective Technological Studies Production and Consumption Unit, Sevilla, Spain.

Lutz C, Meyer B, Nathani C, Schleich J. Endogenous technological change and emissions: The case of the German steel industry. Energy Policy 2005;33(9):1143-54.

Meunier, G. and J-P. Ponssard (2011): A Sectoral Approach Balancing Global Efficiency and Equity. Working Paper, revised version, August 2011.

Peterson, E. and H. Lee (2009). “Implications of Incorporating Domestic Margins into Analyses of Energy Taxation and Climate Change.” Economic Modelling 26 (2),370–378.

Peterson, E.B., J. Schleich, and V. Duscha (2011). “Environmental and Economic Effects of the Copenhagen Pledges and More Ambitious Emission Reduction Targets.” Energy Policy 39 (2011): 3697-3708.

Schumacher K, Sands RD. Where are the industrial technologies in energy–economy models? An innovative CGE approach for steel production in Germany. Energy Economics 2007;29(4):799-825.

Tuerk, A., M. Mehling, C. Flachsland and W. Sterk (2009), “Linking carbon markets: concepts, case studies and pathways”, Climate Policy 9, 341-357.

Voigt, S., Alexeeva-Talebi, V. and Löschel, A. (2011): Macroeconomic Impacts of Sectoral Approaches: The Role of the Cement Sector in China, Mexico and Brazil, 34th IAEE International Conference, Stockholm, 22 June, 2011.

Wooders, P. (2010), International sectoral approaches and agreements: case studies of the steel sector in China, India and Japan { Emerging Policy Recommendations. Climate Strategies.

World Business Council for Sustainable Development (WBCSD) (2009), A sectoral approach. Cement Sustainability Initiative.

Burniaux, J.-M., Truong, P., 2002. GTAP-E: An Energy-Environmental Version of the GTAP Model. GTAP Technical Paper No. 16 (Revised), January.

Ianchovichina, E., Walmsley, T. Global Economic Analysis: Dynamic Modeling and Applications. Forthcoming.

Kemfert, C., 1998. Estimated substitution elasticities of a nested CES production function for Germany, Energy Economics, 20, 249 – 264.

Kemfert, C., Truong, T., 2007. Impact assessment of emissions stabilization scenarios with and without induced technological change. Energy Policy 35, 5337-5345.

Table 1: Overview of global crude steel production in 2010

Region	Total production of crude steel (in 1000 tonnes)	Share of global crude steel production	Share of EAF steel
China	626 654	44%	10%
EU27	172 636	12%	42%
EU15	147 478	10%	44%
EU12	25 158	2%	32%
Japan	109 599	8%	22%
United States	80 495	6%	61%
India	68 300	5%	60%
Russia	66 940	5%	27%
Rest Asia	98 377	7%	54%
South America	43 873	3%	34%
CIS excl. Russia	41 149	3%	12%
Other Europe	33 595	2%	70%
North America excl. US	30 911	2%	59%
Middle East	19 595	1%	88%
Africa	16 615	1%	67%
Oceania	8 149	1%	18%
Global	1 416 887		29%

Source: World Steel (2011).

Table 2: Value of Steel Output by Production Process for GTAP v.7 Database

Region	BOF	EAF	Total
		$millions, 2004	
Australia	10,161.0	2,523.6	12,684.6
China	148,837.1	26,666.2	175,503.2
Japan	124,484.4	44,661.1	169,145.4
South Korea	32,767.1	25,659.4	58,426.5
Indonesia	2.2	2,217.7	2,220.0
India	16,395.6	12,794.4	29,190.0
Canada	9,939.3	6,852.8	16,792.2
United States	63,163.9	68,796.8	131,960.6
Mexico	2,975.2	7,481.6	10,456.8
Argentina	1,313.5	1,392.6	2,706.1
Brazil	18,658.3	5,659.0	24,317.3
France	22,272.0	14,006.7	36,278.7
Germany	33,738.3	14,914.6	48,652.8
Italy	29,664.8	29,664.8	59,329.5
Spain	5,044.4	16,053.9	21,098.3
United Kingdom	17,710.1	5,145.2	22,855.3
BOF15	35,138.5	7,603.0	42,741.5
Rest of EU15	4,836.1	10,932.6	15,768.6
BOF12	15,691.2	4,111.3	19,802.5
Rest of EU12	4,456.7	4,890.5	9,347.1
Switzerland	4.7	4,683.5	4,688.2
Norway	2.2	2,229.6	2,231.9
Russis	19,797.5	5,242.0	25,039.5
Ukraine	6,060.7	827.5	6,888.2
Turkey	3,823.3	9,601.5	13,424.8
Egypt	481.5	1,328.0	1,809.5
South Africa	6,484.6	5,960.6	12,445.3
Rest of Annex I	4,557.2	1,607.9	6,165.1
Rest of non-Annex I Developed Countries	15,874.9	18,913.0	34,787.9
Rest of Advanced Developing Countries	5,702.7	17,809.0	23,511.6
Rest of Developing Countries	847.6	13,279.0	14,126.6
Rest of Least Developed Countries	2,332.2	412.2	2,744.4

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

Table 3: Forecast Growth in CO_2 Emissions by Region

Region	2012	Growth Rate	
	Mill MT	Percent change	
Australia	406.4	2.62	1.32
China	8,084.1	17.02	10.60
Japan	1,086.1	3.26	1.05
South Korea	543.7	4.85	-2.11
Indonesia	434.0	11.51	8.04
India	1,745.3	16.81	11.17
Canada	554.6	6.93	5.14
United States	5,454.7	1.08	-0.41
Mexico	444.5	9.78	2.94
Argentina	190.3	6.43	6.58
Brazil	423.6	15.53	10.44
France	361.3	1.83	-0.74
Germany	768.9	-2.22	-1.80
Italy	408.4	1.46	1.00
Spain	309.3	7.75	3.47
United Kingdom	479.5	-0.15	-0.56
BOF15	394.2	4.31	2.94
Rest of EU15	296.1	4.56	2.99
BOF12	595.5	5.44	4.04
Rest of EU12	114.8	2.05	1.70
Switzerland	43.1	-2.40	-2.73
Norway	40.0	2.75	-1.36
Russis	1,643.0	4.87	3.58
Ukraine	311.9	9.25	4.23
Turkey	294.7	10.12	12.80
Egypt	199.3	11.25	5.55
South Africa	341.2	1.55	-1.03
Rest of Annex I	353.8	11.65	12.50
Rest of non-Annex I Developed Countries	1,276.4	11.21	14.61
Rest of Advanced Developing Countries	1,470.4	10.86	12.19
Rest of Developing Countries	787.6	12.87	12.42
Rest of Least Developed Countries	406.3	21.38	13.93

Source: POLES Forecast.

Table 4: BOF Steel Output Changes Across Scenarios

		2013-2016					
		Policy/Forecast			Carbon Tax ($/MT)		
Region	Forecast	Single	Sector	Linked	Single	Sector	Linked
aus	9.1	1.3	1.1	1.0	8.3	24.7	5.0
chn	62.5	-0.8	-0.8	-0.8	6.5	11.8	5.7
jpn	5.3	-1.0	-1.1	-1.1	26.1	35.0	17.7
kor	22.6	-0.4	-1.2	-1.0	21.7	28.9	12.2
idn	30.2	-6.2	-2.3	-0.6	16.7	18.1	9.4
ind	51.7	-1.1	-1.4	-1.3	7.9	9.3	5.0
can	3.7	1.0	0.8	1.1	17.1	27.8	9.6
usa	8.7	-0.1	-0.1	-0.2	15.9	27.2	9.3
mex	18.0	-3.2	-2.1	-2.1	27.0	23.4	18.1
arg	12.5	0.5	1.7	1.1	14.5	9.2	8.6
bra	5.1	-1.8	-0.7	-1.4	34.3	17.5	16.1
fra	5.3	-0.3	0.2	-0.8	48.5	43.7	33.3
deu	6.2	-0.3	-0.3	-0.3	22.4	43.2	11.7
ita	15.4	-1.2	-1.3	-1.2	35.1	46.3	18.8
esp	9.8	-0.9	-1.9	-0.3	25.7	36.9	13.8
gbr	6.5	1.2	0.7	1.1	21.6	64.0	12.4
bof15	3.2	0.4	0.2	-0.2	38.3	50.6	23.3
reu15	8.3	0.5	0.7	0.4	23.2	56.4	12.2
bof12	21.8	-1.0	-2.1	-1.0	12.5	24.2	8.4
reu12	16.7	0.2	0.5	-0.4	16.5	30.3	11.6
che	4.2	1.1	3.1	0.8	57.4	68.6	47.0
nor	1.5	5.0	7.8	7.9	44.8	51.8	29.3
rus	53.5	-1.2	-1.0	-0.8	19.3	28.9	17.2
ukr	19.2	-4.2	-4.6	-3.6	15.6	19.0	11.7
tur	14.9	-1.4	-1.5	-1.3	16.4	18.5	10.8
egy	17.2	-10.5	-6.9	-5.4	16.7	15.5	11.5
zaf	5.2	1.7	1.8	0.7	5.4	7.4	3.7
xa1	7.4	-0.1	0.2	0.3	10.6	11.6	7.3
xna1d	23.0	-0.1	-0.2	0.9	24.2	34.8	18.9
xad	11.0	-2.0	1.1	0.4	21.2	19.0	13.8
xod	22.3	-4.4	-1.6	-2.6	19.2	17.6	12.9
xldc	32.3	-3.4	-2.7	-1.8	24.6	28.7	16.3

Table 4: Continued

		2017-2020					
		Policy/Forecast			Carbon Tax ($/MT)		
Region	Forecast	Single	Sector	Linked	Single	Sector	Linked
aus	7.4	1.5	1.5	1.4	13.3	42.1	6.3
chn	37.2	-0.5	-0.5	-0.4	9.2	20.4	7.5
jpn	1.9	-0.8	-0.9	-0.9	39.3	58.0	24.7
kor	16.3	-0.5	-1.5	-1.2	40.0	52.6	19.2
idn	42.1	-9.5	-4.6	-3.0	27.7	28.2	13.4
ind	48.7	-1.0	-1.7	-1.8	15.2	17.5	8.0
can	-0.8	1.3	1.2	1.5	25.6	40.0	13.3
usa	6.6	0.0	0.0	-0.1	24.9	43.5	12.6
mex	8.4	-3.3	-2.0	-2.2	40.1	34.8	25.9
arg	9.3	0.3	1.8	1.1	22.7	13.7	12.6
bra	7.2	-1.4	-0.6	-1.3	53.3	29.4	26.6
fra	5.2	-0.2	0.5	-0.7	79.4	77.7	53.5
deu	5.5	-0.1	-0.2	0.0	38.1	77.5	17.0
ita	13.9	-1.4	-1.5	-1.2	54.6	77.9	27.4
esp	4.8	-0.3	-1.5	0.6	44.4	66.0	21.4
gbr	5.7	1.5	0.7	1.3	36.9	117.0	17.7
bof15	2.3	0.6	0.4	0.0	60.0	84.6	33.7
reu15	8.8	0.6	0.9	0.5	39.2	100.9	17.6
bof12	21.3	-1.4	-2.9	-1.3	20.2	43.3	12.1
reu12	15.3	0.7	1.3	0.1	28.9	56.9	19.2
che	4.6	1.4	3.9	1.1	98.2	141.4	87.6
nor	0.3	4.5	3.9	6.6	66.8	106.7	41.4
rus	50.1	-2.5	-2.2	-2.5	30.9	45.9	26.5
ukr	11.9	-4.3	-5.3	-3.3	24.8	32.9	17.2
tur	26.9	-0.9	-1.4	-0.7	25.7	32.6	15.1
egy	29.7	-12.5	-7.9	-9.8	25.5	22.6	19.8
zaf	4.4	0.5	1.1	-0.4	7.5	11.6	4.4
xa1	0.5	0.8	0.7	1.4	15.6	18.4	9.7
xna1d	21.3	-1.0	-1.1	-0.1	33.0	48.8	24.3
xad	6.6	-2.8	0.1	0.2	30.4	28.5	17.6
xod	20.1	-5.4	-2.4	-3.4	26.8	25.1	16.2
xldc	32.3	-4.5	-3.8	-3.1	35.3	40.6	22.0

Table 5: EAF Steel Output Changes Across Scenarios

		2013-2016					
		Policy/Forecast			Carbon Tax ($/MT)		
Region	Forecast	Single	Sector	Linked	Single	Sector	Linked
aus	-2.1	4.9	2.4	4.4	8.3	24.7	5.0
chn	86.7	-1.4	-1.0	-1.7	6.5	11.8	5.7
jpn	2.3	0.1	0.1	-0.3	26.1	35.0	17.7
kor	12.6	-1.0	-0.9	-1.1	21.7	28.9	12.2
idn	20.6	-2.8	-1.7	0.6	16.7	18.1	9.4
ind	54.2	-0.5	-1.0	-1.4	7.9	9.3	5.0
can	2.4	1.4	0.0	1.9	17.1	27.8	9.6
usa	7.9	0.3	-0.1	0.1	15.9	27.2	9.3
mex	17.2	-2.9	-1.6	-1.6	27.0	23.4	18.1
arg	1.3	-8.5	-2.4	-3.1	14.5	9.2	8.6
bra	-2.8	1.1	2.6	1.8	34.3	17.5	16.1
fra	3.1	1.9	1.8	0.6	48.5	43.7	33.3
deu	5.3	0.0	-0.8	0.2	22.4	43.2	11.7
ita	14.6	-1.9	-2.4	-2.0	35.1	46.3	18.8
esp	14.5	-0.2	-0.3	-0.3	25.7	36.9	13.8
gbr	5.6	1.5	0.6	1.3	21.6	64.0	12.4
bof15	3.3	0.5	-0.5	0.0	38.3	50.6	23.3
reu15	4.8	2.0	0.7	1.6	23.2	56.4	12.2
bof12	20.6	-1.7	-2.1	-1.5	12.5	24.2	8.4
reu12	18.3	0.3	-0.2	-0.4	16.5	30.3	11.6
che	2.6	1.7	1.9	1.3	57.4	68.6	47.0
nor	-0.2	5.8	6.6	7.9	44.8	51.8	29.3
rus	25.0	-9.0	-9.1	-6.4	19.3	28.9	17.2
ukr	21.5	-6.9	-8.5	-4.3	15.6	19.0	11.7
tur	15.4	-0.7	-0.2	-0.8	16.4	18.5	10.8
egy	10.2	0.4	2.0	1.6	16.7	15.5	11.5
zaf	10.2	1.2	0.8	0.6	5.4	7.4	3.7
xa1	21.8	4.0	4.9	3.7	10.6	11.6	7.3
xna1d	14.9	0.4	1.1	1.1	24.2	34.8	18.9
xad	15.9	0.2	0.8	0.8	21.2	19.0	13.8
xod	17.4	-2.0	-1.4	-1.0	19.2	17.6	12.9
xldc	21.5	-3.6	-4.0	-0.9	24.6	28.7	16.3

Table 5: Continued

		2017-2020					
		Policy/Forecast			Carbon Tax ($/MT)		
Region	Forecast	Single	Sector	Linked	Single	Sector	Linked
aus	-9.5	6.1	3.7	6.4	13.3	42.1	6.3
chn	51.8	-1.4	-1.1	-1.9	9.2	20.4	7.5
jpn	-2.5	0.8	0.9	0.7	39.3	58.0	24.7
kor	5.7	-1.1	-1.1	-1.1	40.0	52.6	19.2
idn	24.4	-4.7	-3.0	-0.4	27.7	28.2	13.4
ind	53.5	-0.7	-1.7	-2.3	15.2	17.5	8.0
can	-1.1	1.4	0.0	2.4	25.6	40.0	13.3
usa	5.0	0.5	0.1	0.3	24.9	43.5	12.6
mex	9.7	-3.5	-2.1	-2.0	40.1	34.8	25.9
arg	2.0	-8.9	-2.2	-2.8	22.7	13.7	12.6
bra	-0.5	1.7	3.3	2.6	53.3	29.4	26.6
fra	0.7	2.7	2.6	1.3	79.4	77.7	53.5
deu	3.4	0.2	-0.9	0.7	38.1	77.5	17.0
ita	11.1	-2.0	-2.6	-1.8	54.6	77.9	27.4
esp	12.8	0.1	0.1	0.0	44.4	66.0	21.4
gbr	5.3	1.9	0.9	1.8	36.9	117.0	17.7
bof15	3.0	0.8	-0.4	0.3	60.0	84.6	33.7
reu15	3.9	2.6	1.2	2.3	39.2	100.9	17.6
bof12	19.1	-2.0	-2.5	-1.5	20.2	43.3	12.1
reu12	17.3	0.5	0.0	-0.2	28.9	56.9	19.2
che	2.6	2.1	2.5	1.8	98.2	141.4	87.6
nor	-1.9	5.5	3.4	7.0	66.8	106.7	41.4
rus	25.9	-10.5	-10.3	-7.6	30.9	45.9	26.5
ukr	14.8	-7.8	-10.8	-4.1	24.8	32.9	17.2
tur	24.6	-0.5	0.2	-0.4	25.7	32.6	15.1
egy	25.6	-0.8	1.2	0.2	25.5	22.6	19.8
zaf	5.1	0.6	0.4	0.1	7.5	11.6	4.4
xa1	17.4	4.7	5.6	4.3	15.6	18.4	9.7
xna1d	15.9	-0.1	0.6	0.6	33.0	48.8	24.3
xad	14.2	-0.5	0.0	0.2	30.4	28.5	17.6
xod	13.7	-2.3	-1.6	-0.9	26.8	25.1	16.2
xldc	21.4	-4.3	-4.8	-1.4	35.3	40.6	22.0