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Abstract

Intensity standards have gained substantial momentum as a regulatory instrument in US climate policy. Based on numerical simulations with a large-scale computable general equilibrium model we show that intensity standards may rather increase than decrease counterproductive carbon leakage. Moreover, standards can lead to considerable welfare losses compared to emission pricing via carbon taxation or an emissions trading system. The tradability of standards across industries is a mechanism that can reduce these negative effects.

JEL classification: D21, H23, D58

Key words: Unilateral climate policy; carbon leakage; intensity standards; computable general equilibrium

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1. INTRODUCTION

Intensity standards are becoming increasingly popular in numerous countries as a means of controlling carbon emissions (Jotzo and Pezzey 2007; Sawyer and Gass 2013) while there is little progress in explicit pricing of emissions via taxes or emission allowances at the nationwide level (Roelfsema et al. 2014). As a primary example, intensity standards gain substantial momentum in the domestic US climate policy debate. In 2012 an intensity energy standard was proposed within the Clean Energy Standard Act; furthermore, the Environmental Protection Agency (EPA) put forward a plan under the Clean Air Act to reduce emissions from existing power plants using carbon intensity standards (Burtraw et al. 2012). The objective of EPA's Clean Power Plan is to reduce CO_2 emissions intensity by 30 percent below 2005 levels by 2030 at the national level – US states will have to meet specific carbon intensity standards but could potentially use flexibility mechanisms such as tradability of standards in order to reduce overall compliance costs.

From the perspective of cost-effectiveness, economists generally favor market-based instruments such as carbon taxes or tradable emission allowances over command-and-control instruments such as emission intensity standards (Hahn 1989). Standard textbook analysis postulates the efficiency rationale of uniform emission taxes or tradable emission allowances to achieve emission reduction at lowest cost. However, this view might be overly simplistic in a second-best setting where additional constraints are taken into account. One obvious constraint is political economy where the distribution of regulatory costs and benefits across stakeholders matters and trade-offs with efficiency objectives can't be easily resolved through lump-sum transfers (Oates and Portney 2003).

Intensity standards work as implicit emission taxes on the input side where the fictitious tax revenues are recycled as implicit subsidies on the output side (Holland et al. 2009). Thus, industrial stakeholders prefer standards over explicit emission pricing, where the rents in terms of taxes or auctioning revenues typically go to the government and thus are perceived as lost from the individual firm perspective.[1] While efficiency standards could be designed to achieve uniform emission pricing on the input side – having them defined on emissions rather than on energy and making them tradable – the output subsidy mechanism in general leads to

[1] Note that rebating scarcity rents of environmental regulation to industries can be also an important feature to promote political feasibility of market-based instruments. Prominent examples are the SO_2 allowance trading scheme under the Clean Air Act (Stavins 1998 and Burtraw 1999) or the EU carbon emission trading scheme (Böhringer and Lange 2013) which involve the free allocation of emission allowances. Another early example is Sweden's NO_X tax, where revenues are rebated to affected power plants in proportion to the amount of energy produced (OECD 2001).

inefficiently high output levels; as a consequence, one loses cost-effectiveness compared to a first-best setting.

Apart from political feasibility and concerns on the incidence of regulation, there are more sophisticated efficiency reasons why intensity standards might be preferable to emission taxes or tradable emission allowances. Essentially, such reasons root in second-best situations due to pre-existing market distortions (and market failures) or incomplete coverage of regulatory control. A prevailing case for initial market distortions are taxes to finance the provision of public goods. According to Goulder et al. (2014), intensity standards might become superior to emission pricing if standards are set sufficiently low. The reasoning behind is that factor markets get less distorted through intensity standards since the latter constitute a smaller implicit tax on factors. The efficiency properties of intensity standards thereby depend on the nature and extent of prior tax distortions as well as the stringency and design of the intensity standards themselves.

This paper investigates another potential efficiency rationale for the use of intensity standards: carbon leakage due to incomplete regulatory coverage of a global externality. Carbon leakage occurs in fragmented or unilateral climate regimes when emissions in regions without (or with laxer) regulation increase as a result of climate policies in regions with stringent emission controls. Leakage occurs mainly through two intertwined channels (Felder and Rutherford 1993): the trade channel and the international fossil fuel market channel. The trade channel is driven by changes in competitiveness of energy-intensive and trade-exposed industries that could relocate from regions with higher to regions with lower regulatory stringency. The fossil fuel market channel is driven by demand reductions for fossil fuels in countries with binding emission constraints – the associated drop in international fossil fuel prices triggers additional fuel demands in countries without emission regulation.

In a situation with international climate policy fragmentation, uniform emission pricing of CO_2 emissions is no longer a first-best setting. Second-best policies may be justified to counteract leakage and increase the global cost-effectiveness of unilateral action (see Kuik and Gerlagh 2003 or Babiker and Rutherford 2005). The economic literature has suggested various policy instruments such as carbon tariffs, sector-specific emission pricing or tax exemptions, and output-based rebates (see Böhringer et al. 2012 for a more recent meta-study). While all these instruments can be justified as second-best anti-leakage measures, they come along with distortions of their own and thereby run – if not accurately designed – the risk of even higher cost than uniform emission pricing stand-alone (see e.g Antimiani et al. 2013 or Böhringer et al. 2014). In the context of carbon leakage, Holland (2012) has done theoretical analysis to explore when carbon pricing may become inferior to intensity standards. He shows that intensity standards can in principle prevent leakage and foster cost-effectiveness of unilateral emission reduction as compared to emission pricing via taxes or tradable emission allowances.

Our study complements the theoretical partial equilibrium work by Holland (2012) with empirical analysis using real data and accounting for complex market interaction and feedback effects. We use a large-scale computable general equilibrium model of the global economy to investigate the economic and emission effects across alternative designs of unilateral intensity standards implemented by the US. We find that intensity standards bear the risk to increase rather than decrease carbon leakage and induce substantial excess cost as compared to explicit emission pricing via emission taxes or tradable emission allowances. Stringent intensity standards for energy-intensive and trade-exposed industries can render these sectors less competitive and thus more prone to carbon leakage as compared to an emission tax. In addition to higher emission leakage, inappropriate stringency levels can also cause substantial welfare losses. Tradability of emission standards is an important feature to improve their economic performance.

The remainder of this paper is organized as follows. Section 2 develops a partial equilibrium analytical framework to study the links between carbon leakage and emission standards. Section 3 summarizes the basic structure and parametrization of the computable general equilibrium model used for the applied simulation analysis. Section 4 lays out the core policy scenarios and discusses simulation results. Section 5 concludes.

2. THEORETICAL CONSIDERATIONS

In this section we adapt the partial equilibrium model of Böhringer et al. (2014) to compare the effects of intensity standards and carbon taxes on emission leakage. For the sake of simplicity, we focus on two countries (regions) which differ only with respect to potential regulatory action: country M with emission regulation and country N without emission regulation. Demand q_{ik} in country i for the good produced in country k exhibits constant elasticities with respect to prices and, thus, final demands are given by:

$$q_{MM} = ap_{MM}^{-\eta_0} p_{MN}^{\eta_x}; \qquad q_{MN} = ap_{MN}^{-\eta_0} p_{MM}^{\eta_x};$$

$$q_{NM} = ap_{NM}^{-\eta_0} p_{NN}^{\eta_x}; \qquad q_{NN} = ap_{NN}^{-\eta_0} p_{NM}^{\eta_x}.$$

The benchmark demand is denoted by a (as initial prices are normalized to unity), η_o is the own-price elasticity, and η_x is the cross-price elasticity. Production in each country is the sum of demand from the regulated and non-regulated country:

$$y_M = q_{MM} + q_{NM}; \qquad y_N = q_{MN} + q_{NN}.$$

Global emissions are:

$$GE = E_M + E_N = \mu_M y_M + \mu_N y_N.$$

The emission intensity in country *i* is denoted by μ_i and emissions in country *i* are given by E_i.

Following Böhringer et al. (2014) we refer to carbon leakage as the emission change in the non-regulated country over the emission change in the regulated country:

$$L = \frac{E_N}{E_N^0} \Big/ \frac{E_M}{E_M^0}$$

We assume competitive markets, so prices equal marginal costs plus potential taxes. Marginal production cost $c(\mu)$ is constant with respect to output and increasing as the intensity of emissions μ decreases (i.e. c'<0). Let $\mu(t)$ denote the cost-minimizing emission intensity at carbon price t. In the benchmark t=0, with $\mu_0=\mu(0)$ indicating the initial emissions intensity and normalizing $p_0=c(\mu_0)=1$. We further note that, given any positive carbon price, t>0, producers decrease their emission intensity to lower compliance costs, so $1 + t\mu_0 > c\big(\mu(t)\big) + t\mu(t)$.

When a carbon tax (t>0) is set (Tax: sub-/superscript T), the regulated producer adjust their intensities and prices are equal to marginal costs plus taxes. Thus, $p_{MM}=p_{NM}=c_T+t\mu_T$, where $c_T=c(\mu_T)$ and $\mu_T=\mu(t)$. Meanwhile in the non-regulated country, $p_{MN}=p_{NN}=c_0=1$. Consequently production in the regulated and non-regulated country is given by:

$$y_M^T = 2a(c_T + t\mu_T)^{-\eta_0}; \qquad y_N^T = 2a(c_T + t\mu_T)^{\eta_x}.$$

Emissions increase in the regulated country while they decrease in the non-regulated country:

$$\frac{E_M^T}{E_M^0} = \frac{\mu_T y_M^T}{\mu_0 y_M^0} = \frac{\mu_T}{\mu_0}(c_T + t\mu_T)^{-\eta_0} < 1; \qquad \frac{E_N^T}{E_N^0} = \frac{y_N^T}{y_N^0} = (c_T + t\mu_T)^{\eta_x} > 1.$$

Carbon leakage then is given by:

$$L^T = \frac{E_N^T}{E_N^0} \Big/ \frac{E_M^T}{E_M^0} = (\mu_0/\mu_T)(c_T + t\mu_T)^{\eta_x+\eta_0} > 1.$$

A carbon price reduces emissions in the regulated country by reducing emission intensity[2] and output[3], while it increases emissions in the non-regulated country by expanding output. Therefore, the leakage rate increases when a carbon tax is set.

Next we analyze how intensity standards affect the carbon leakage rate (Standard: sub-/superscript S). Let $\bar{\mu}$ represent the intensity standard, which is below the benchmark

[2] As argued above, producers decrease their emission intensity to lower compliance costs, so $\mu_T < \mu_0$.
[3] $\mu_T < \mu_0$, which implies $c_T > c_0$ and, consequently, $c_T + t\mu_T > c_0$.

emissions intensity (i.e. $\bar{\mu} < \mu_0$). Firms will reduce their emission intensity until $\mu_S = \bar{\mu}$. Thus, p_{MM}=p_{NM}=c_S, where c_S=$c(\mu_S)$ and $\mu_S = \bar{\mu}$. Meanwhile in the non-regulated country, p_{MN}=p_{NN}=c_0=1. Production in the regulated and the non-regulated countries is given by:

$$y_M^S = 2a(c_S)^{-\eta_0}; \qquad y_N^S = 2a(c_S)^{\eta_x}.$$

Emissions increase in the regulated country while they decrease in the non-regulated country:

$$\frac{E_M^S}{E_M^0} = \frac{\mu_S y_M^S}{\mu_0 y_M^0} = \frac{\mu_S}{\mu_0}(c_S)^{-\eta_0} < 1; \qquad \frac{E_N^S}{E_N^0} = \frac{y_N^S}{y_N^0} = (c_S)^{\eta_x} > 1.$$

Carbon leakage is given by:

$$L^S = \frac{E_N^S}{E_N^0} \Big/ \frac{E_M^S}{E_M^0} = (\mu_0/\mu_S)(c_S)^{\eta_x+\eta_0} > 1.$$

As with carbon prices, an intensity standard reduces emissions in the regulated country by reducing emission intensity ($\mu_S < \mu_0$) and output, while it increases emissions in the non-regulated country by expanding output. Therefore, the leakage rate increases when an intensity standard is set.

So far, we have shown that both a carbon tax and an intensity standard raise the carbon leakage rate with respect to a non-policy scenario. Now, we analyze which policy leads to a higher carbon leakage rate. Carbon leakage triggered by a carbon tax is higher than that of an intensity standard when $L^T/L^S > 1$. Given that the benchmark scenario is the same for both policies we obtain:

$$L^T/L^S = \frac{E_N^T}{E_N^S} \Big/ \frac{E_M^T}{E_M^S} = \frac{y_N^T}{y_N^S} \Big/ \frac{\mu_T y_M^T}{\mu_S y_M^S} = \frac{\mu_S}{\mu_T}\left(\frac{c_S}{c_T + t\mu_T}\right)^{-\eta_0-\eta_x}.$$

When the intensity standard is equal to or higher than the intensity associated with a carbon tax (i.e. $\mu_s \geq \mu_T$), carbon leakage is higher under a carbon tax than under an intensity standard[4] (i.e. $L^T/L^S > 1$). On the other hand, when the intensity standard is lower than the intensity associated with a carbon tax (i.e. $\mu_s < \mu_T$), the effect on carbon leakage is ambiguous. This shows that overly ambitious intensity standard policies (i.e., very low intensity standards) can be counterproductive in terms of reducing carbon leakage as compared to the tax policy case.

3. COMPUTABLE GENERAL EQUILIBRIUM MODEL: STRUCTURE AND DATA

Our stylized partial equilibrium analysis provides insights into basic leakage mechanisms of unilateral regulation via explicit emission pricing and intensity standards. To keep analytical

[4] Notice that $\mu_s > \mu_T$ implies that $c_s < c_T$.

tractability, the partial equilibrium framework abstains from more subtle real-world complexities. Economic adjustment to emission regulation climate policy is driven by comprehensive substitution, output, and income effects across multiple markets following changes in relative prices. In this context, computable general equilibrium (CGE) models have become the standard tool for numerical economy-wide analysis of policy regulation. A computable general equilibrium approach based on empirical data enables us to assess the relative importance of partial equilibrium effects and come up with “real” numbers for informed decision making.

A non-technical summary of our CGE model and its parameterization is provided below. A detailed algebraic model formulation is given in the Appendix.

3.1 Model structure

We use a standard multi-sector, multi-region static CGE model of global trade and energy use (see Böhringer and Rutherford 2002 for the generic model structure).

The representative agent in each region receives income from three primary factors: labor, capital and fossil fuel resources (coal, gas and crude oil). Labor and capital are mobile across sectors within a region but immobile between regions. Fossil fuel resources are specific to fossil fuel production sectors in each region. Production is captured by nested constant elasticity of substitution (CES) cost functions describing the price-dependent use of capital, labor, energy and material in production (see Figure A1.). At the top level, a CES composite of intermediate material demands trades off with an aggregate of energy, capital, and labor. At the second level, a CES function describes the substitution possibilities between intermediate demand for the energy aggregate and a value-added composite of labor and capital. Finally, at the third level, a CES function captures capital and labor substitution possibilities within the value-added composite, whereas different energy inputs (coal, gas, oil and electricity) enter the energy composite subject to a CES. In the production of fossil fuels (see Figure A2.) all inputs except the sector-specific fossil fuel resource are aggregated in fixed proportions; this aggregate trades off with the sector-specific fossil fuel resource at a CES.

Final consumption demand in each region is determined by a representative household that maximizes utility subject to a budget constraint with fixed investment and exogenous government provision of public goods and services. The household’s total income consists of net factor income and tax revenues. Its consumption demand is given as a CES aggregate that combines consumption of an energy composite and a composite of other goods; a CES function reflects substitution patterns within both of these composites (see Figure A1.).

Bilateral trade is specified following the approach of Armington (1969), i.e. product heterogeneity, in which origin distinguishes all domestic and foreign goods. All goods used on the domestic market in intermediate and final demand correspond to an Armington CES composite that combines the domestically produced good and the imported good (see Figure A3.). The balance-of-payment constraint, which is assured through flexible exchange rates, incorporates the base-year trade deficit or surplus for each region.

The model links carbon dioxide (CO_2) emissions in fixed proportions to the combustion of fossil fuels with fuel-specific CO_2 coefficients. The emission intensity or energy intensity within a sector can be reduced in two ways: by inter-fuel switching or by substituting away from fuels to non-fuel inputs. The cost of reducing intensity thus depends on the substitution elasticities and benchmark production cost shares, which differ across sectors and regions. Total domestic emissions and energy use can also be reduced by structural shifts in production and consumption patterns.

3.2 Data

The model is calibrated to the GTAP 9 dataset which includes detailed national input-output data, bilateral trade information, energy flows, and CO_2 emissions for 140 regions and 57 sectors for 2011 (Narayanan et al. 2015). For our analysis we aggregate the database to 15 sectors and 12 countries (regions) – see Table 1. At the sectoral level, we identify primary and secondary energy carriers (coal, gas, crude oil, refined oil products, and electricity) which are essential to distinguish energy goods by CO_2 and energy content as well as their degree of inter-fuel substitutability. Furthermore, we explicitly include energy-intensive and trade-exposed (EITE) sectors which are central to the policy debate on emission leakage. These EITE sectors cover paper, pulp and print, chemicals, iron and steel; nonferrous metals (including copper and aluminum); and non-metallic minerals (including cement and glass). Note that the refined oil product sector is also attributed to the EITE sectors. The remaining sectors are transport services (air, water, and other transport) and a composite of all the remaining industries and services. At the regional level, we explicitly include the US and its main trading partners to capture the scope of international spillover effects from unilateral emission regulation in the US.

Elasticities in trade (Armington elasticities) are based on empirical estimates reported in the GTAP database. For the substitution elasticities in production between factors capital, labor, energy, and non-energy inputs (materials), we draw on econometric estimates from the panel data analysis conducted by Okagawa and Ban (2008). The elasticities of substitution in fossil fuel sectors are calibrated to match exogenous estimates of fossil fuel supply elasticities (Graham et al. 1999, Krichene 2002, and Ringlund et al. 2008). The GTAP database features a variety of initial tax distortions, including factor taxes, intermediate input taxes, production taxes and subsidies, value-added taxes as well as import tariffs and export duties.

Table 1: Model sectors and regions

Sectors and commodities	Countries and regions
Energy:	*Region with unilateral climate policy:*
Coal	United States
Crude oil	
Natural gas	*Other OECD countries:*
Refined oil products*	Australia and New Zealand
Electricity	Canada
	European Union
*Energy-intensive and trade-exposed (EITE) *:*	Japan
Chemical products	Rest of OECD
Iron and steel industry	
Non-metallic minerals	*Major emerging economies:*
Machinery and equipment	Brazil
Air transport	China
	India
Other industries and services:	
Water transport	*Major oil and gas exporters:*
Other transport	Russian Federation
Other manufactures and services	OPEC
	Other countries and regions:
	Rest of the World

**Refined oil products are included in EITE*

In the 2011 base year CO_2 emissions from the combustion of fossil fuels amounts to 5536 Mt. EITE sectors account for 806 Mt, i.e., 14.6 % of total base year emissions. In terms of their economic weight, the EITE sectors contribute 8.3% to overall value added. According to the GTAP base year data, the EITE CO_2 intensity is in average ca. 3 times higher, the energy intensity ca. 4.5 times higher, and the export intensity 3.5 time higher than for the average other industries and services (excluding electricity production).

4. POLICY SCENARIOS AND SIMULATION RESULTS

4.1 Policy scenarios

Our research interest is in the impact assessment of intensity standards for energy-intensive and trade-exposed (EITE) sectors as a central element of US climate policy design. We distinguish intensity standards along two key dimensions. The first dimension refers to the metric of intensity: emissions versus energy. The second dimension reflects the scope for where-flexibility in compliance: standards which must be fulfilled at the sector level versus standards which can be traded across EITE sectors. The cross-combination of these two dimension yields four variants for intensity policies applied to EITE sectors. Across the four variants, all other non-EITE segments of the US economy are subject to emission pricing. We compare the four scenarios with intensity standards against a reference policy of economy-wide emission pricing. Table 2 provides a summary of the five scenarios for US climate policy design underlying our analysis.

Table 2: Summary of policy scenarios (scenario acronyms in parenthesis)

Reference scenario (*REF*)			
All segments of the economy are subject to a CO_2 emission price to achieve an exogenous CO_2 emission reduction target.			
Intensity scenarios (*ISE*, *ISC*, *ISET*, *ISCT*)			
Energy-intensive and trade-exposed (EITE) sectors face intensity standards instead of an explicit CO_2 emission price. All other segments of the economy are subject to a CO_2 emission price which achieves the same global emission reduction as achieved under the *REF* scenario.			
		Tradability of Standards	
		No	Yes
Metric	Energy	(*ISE*)	(*ISET*)
	CO_2	(*ISC*)	(*ISCT*)

In our central case simulations we assume that the US is committed to a CO_2 emission reduction of 20% compared to business-as-usual emission levels which in our static setting is provided by the 2011 base year. This commitment roughly reflects the order of magnitude of emission reduction that the US made in its post-Kyoto climate policy initiatives.[5]

In the reference scenario the emission reduction target is achieved through uniform CO_2 emission pricing across all segments of the economy. The CO_2 price is either derived as the shadow price of a domestic emission trading system where the cap is set at 80% of the base year emissions; or, the price is given by a CO_2 emission tax set sufficiently high to achieve the 20% emission reduction. Revenues from auctioning emission allowances or taxing emissions

[5] The US has proposed greenhouse gas reduction targets “in the range” of 17% by 2020 and 26-28% by 2025, relative to 2005 emission levels. In the sensitivity analysis we assess the implications of alternative levels of stringency.

are recycled lump-sum to the representative US household. In the intensity scenarios we replace the explicit emission pricing for EITE sectors who instead take over intensity standards. We impose a series of increasingly stringent intensity targets starting from a zero decrease in intensity to a 40% decrease in intensity (compared to the base year intensity level) in discrete steps of 5%.

Given the global public good nature of CO_2 emission reduction, we impose the same global CO_2 emissions constraint across all central case simulations. In this way, the global environmental effectiveness of unilateral US climate policy remains identical, and we can compare alternative policy designs without taking explicitly into account the damages of climate change, which are difficult to quantify. The global emission target is determined by the world-wide CO_2 emission level that emerges from the reference scenario (*REF*) with economy-wide emission pricing to achieve a 20% reduction in domestic US emissions. Keeping with the global emission constraint requires that we scale the unilateral emission reduction target of the US to compensate for policy-induced changes in emission leakage: If complementary intensity targets for EITE sectors will decrease (increase) leakage compared to the reference scenario, then the domestic reduction target will be scaled down (up) accordingly. Across all scenarios, the emission price will attune to the domestic emission reduction target. If emission intensity standards for EITE sectors are relatively lax then the emission price for the remaining segments of the US economy will go up relative to value in the reference scenario with economy-wide emission pricing; likewise, if the intensity targets become very stringent, the emission price for non-EITE sectors will fall below the level of the reference scenario.

4.2 Simulation results

We investigate the implications of alternative designs of intensity standards for EITE sectors compared to the reference scenario without standards where all sectors are subject to a uniform economy-wide emission price. If not stated differently, simulation results are provided as percentage change from the base year values. We first present results for our core simulations and then summarize sensitivity analysis on their robustness.

4.2.1 Core simulation results

Figure 1 reports leakage rates defined as the change of emissions in the rest of the world over the emission reduction in the US. In the *REF* scenario, leakage amounts to less than 5% – in other words: only 5% of the domestic US emission reduction is offset by increases of emissions elsewhere. For the US, leakage thus does not provide a very strong reason to deviate from (first-best) economy-wide emission pricing. We see that modest intensity targets for EITE industries can lower leakage as compared to *REF*. The implicit shadow price of standards on emission and energy use is sufficiently small such that the effective cost burden for EITE industries is lower than in the case of explicit emission pricing. US EITE industries face less severe competitiveness losses which reduces relocation of production and emissions to abroad. However, the leakage reduction for the most favorable case where EITE intensities are kept at base-year levels (a zero intensity decrease) is quite modest. When the stringency of EITE standards goes up to levels that roughly reflect the ambition of the overall CO_2 emission reduction policy (here: 20%), the leakage reduction potential of standards declines further. If on the other hand, intensity standards for EITE industries become tight then leakage is increased rather than decreased. Due to the high implicit tax on energy or emission inputs EITE industries lose out in international competitiveness compared to the *REF* scenario with economy-wide emission pricing.

Figure 1. Carbon leakage (in %)

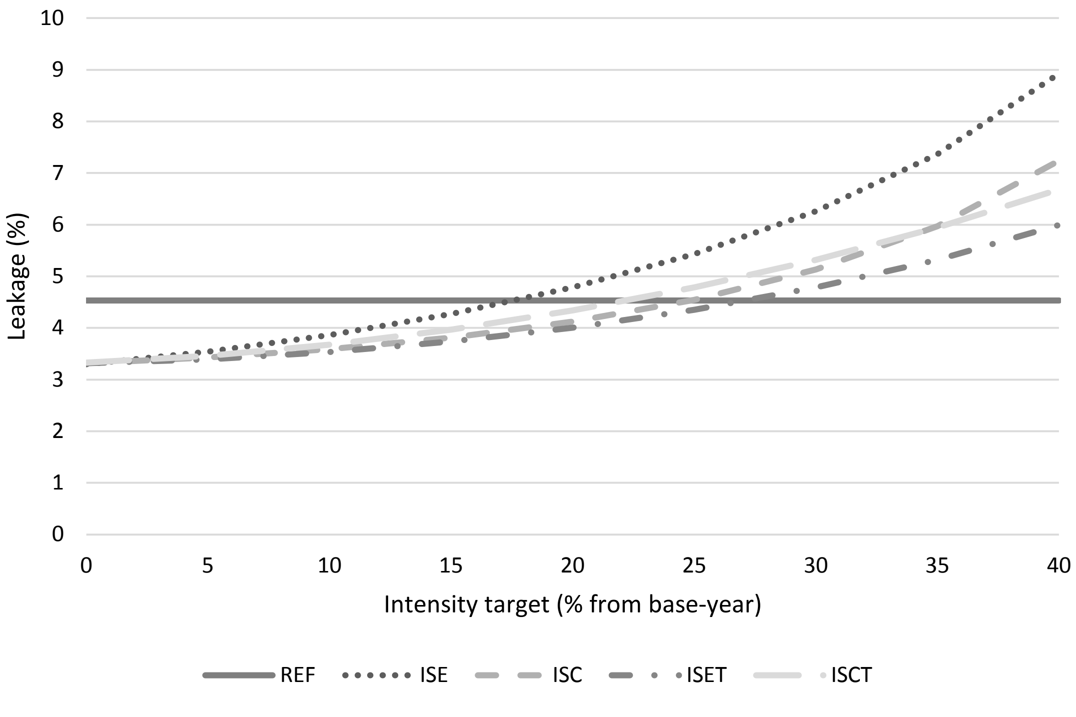
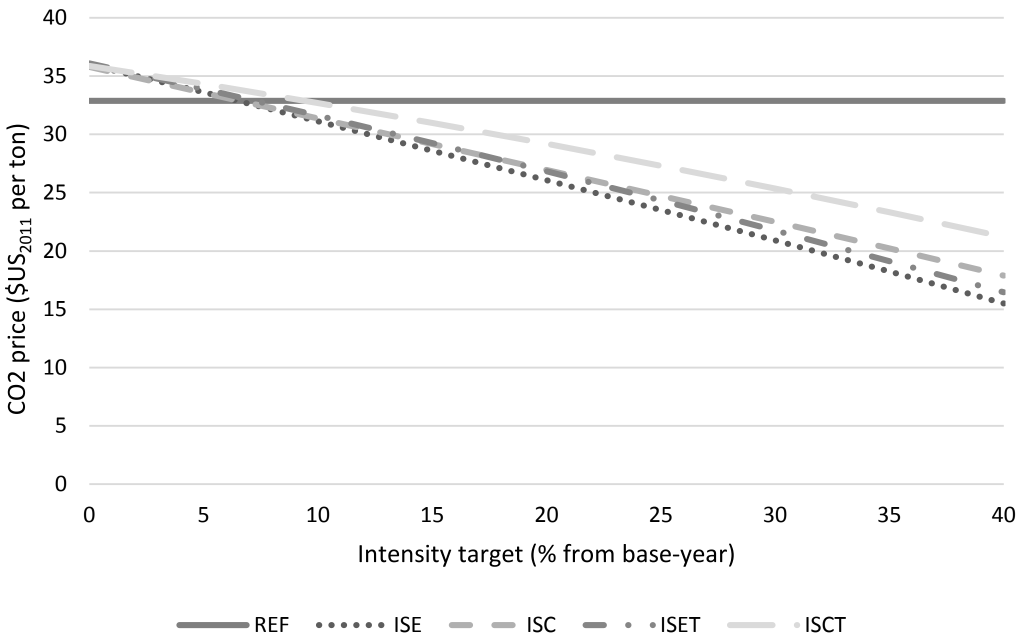


Figure 2 shows the level of the CO_2 emission price across the five policy scenarios. In the *REF* case we have a CO_2 price of 33 $US per ton. When we apply a hybrid regulation where EITE sectors are regulated by standards rather than explicit emission prices the CO_2 price for the remaining segments of the economy changes as a function of the stringency of standards to comply with the overall emission cap. With lax standards, CO_2 prices must be higher to compensate for the smaller CO_2 reduction contribution of EITE sectors. Towards more stringent standards, EITE sectors take over more emission reduction and thus the residual emission reduction requirement for the non-EITE segments goes down. The latter is reflected in decreasing marginal abatement cost, i.e., CO_2 prices. Note that there is a second mechanism in place which affects CO_2 prices in case of standards policies. Whenever the leakage rate changes, the domestic US emission cap to keep with the global emission level obtained under *REF* is endogenously adjusted. As the leakage rate goes down, this implies a downward adjustment of the CO_2 price and the other way round. Given the small leakage rate to start with under *REF* and the rather modest changes of this rate over the range of standards policies (see Figure 1), the importance of this mechanism is however of secondary order.

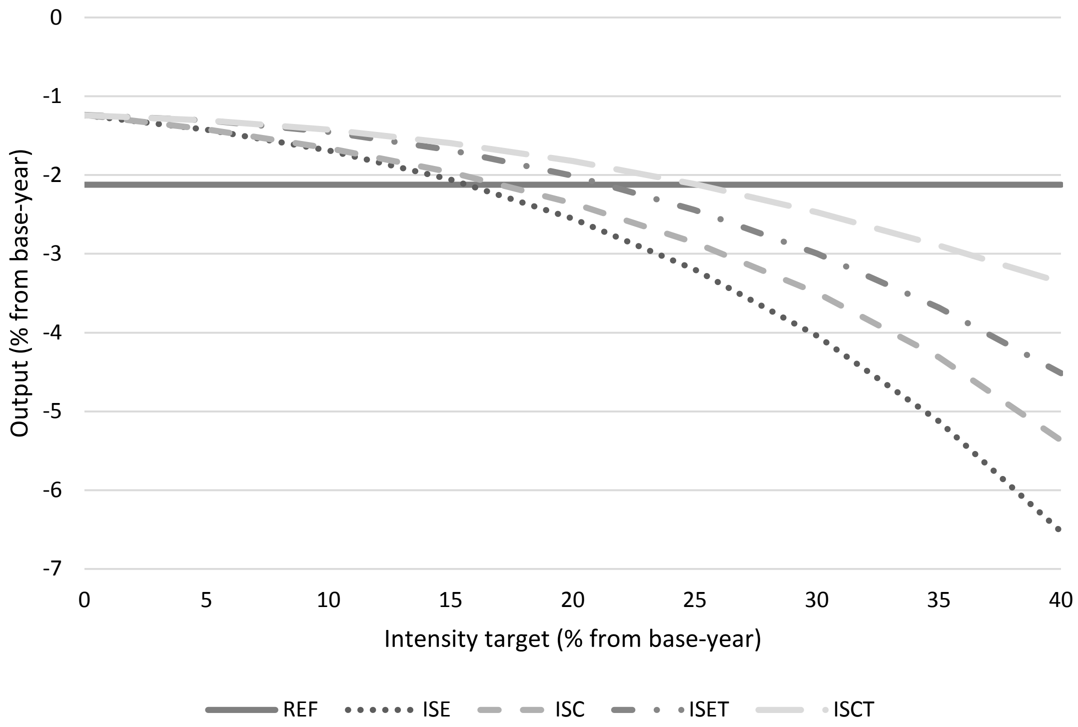
Figure 2. CO_2 price (in $\$US_{2011}$ per ton)



We next turn to the output effects for US EITE industries. A key driver in the US debate on intensity standards is political economy. As climate policy moves from public pledges to tangible measures, EITE industries prefer intensity standards over explicit emission pricing via emission taxes or auctioned allowances. The reason is that they aim to minimize industry-specific adjustment cost through relatively lax standards where regulatory rents are furthermore recycled internally rather than entering the public budget. At the same time, environmental policy has incentives to compromise with influential EITE industries in order to ease and accelerate the legislative process of emission regulation.

Figure 3 shows that the negative repercussions on EITE output triggered by economy-wide emission pricing are modest. In the *REF* scenario, the average decline in output across EITE industries amounts to ca. 2%. Lax standards can reduce the output losses but given the small output shock to start with under *REF* even the political economy rationale for standards are rather meagre.

Figure 3. US output effects for EITE industries (% from base-year)



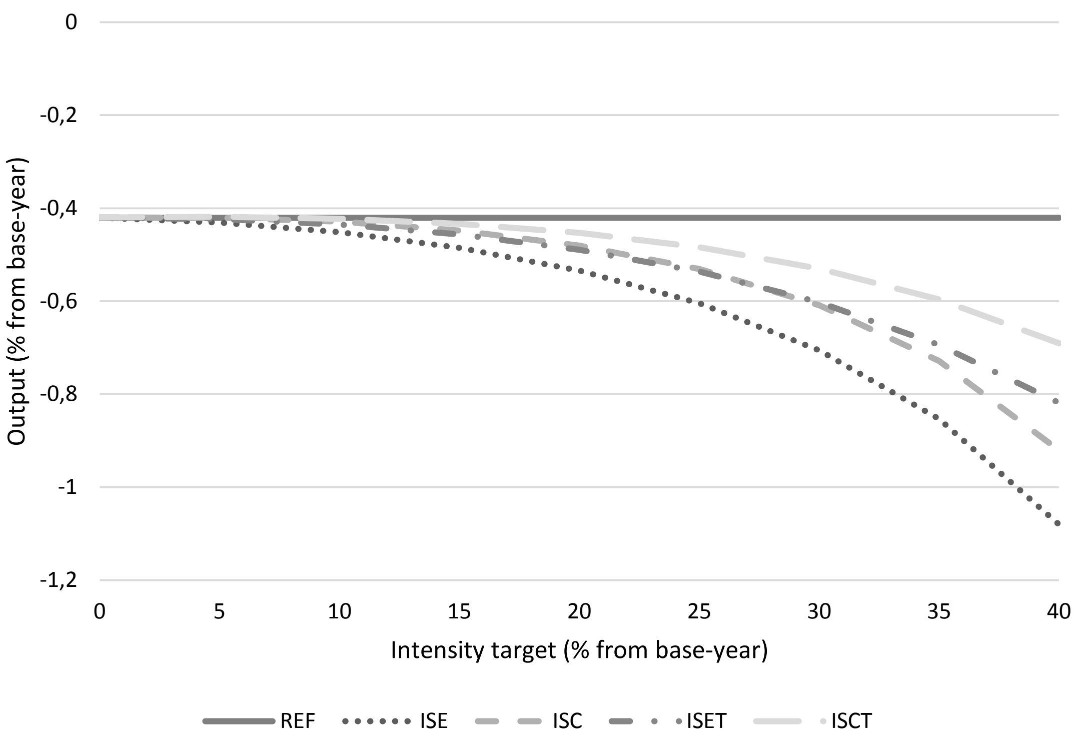
When standards become more and more stringent, EITE industries even run the risk of facing considerable higher output losses as compared to the reference policy of uniform emission pricing. Special regulatory treatment of one sector of the economy – in our case standards instead of explicit emission pricing for EITE industries – typically involves a trade-off with the economic burden put upon the remaining segments of the economy when the regulatory target – here: the CO_2 emission cap – is fixed.[6] We would expect that scaling down the adjustment cost for EITE industries should increase adjustment cost for the rest of the economy and vice versa.

However, Figure 4 shows that more stringent standards for EITE industries do not come as a benefit to production in non-EITE industries. The reasoning behind is that stringent standards

[6] A prime example for such cross-sector burden shifting is the EU emission trading system (ETS) where the initial segmentation of the EU-wide emission cap between energy-intensive sectors covered by the EU ETS and all other sectors led to an over-allocation of emission allowances to ETS sectors. Since emission allowances between ETS sectors and the non-ETS segments of the EU economy are not tradable, the initial segmentation of the emission cap does not boil down to a lump-sum redistribution of adjustment cost; due to differences in marginal abatement costs, EU emission abatement is more costly than necessary (Böhringer et al. 2009).

cause considerable excess cost (see Figure 5 below) that translate into a larger drop in available income such that demand for non-EITE output goes markedly down as well.

Figure 4. US output effects for non-EITE industries (% from base-year)



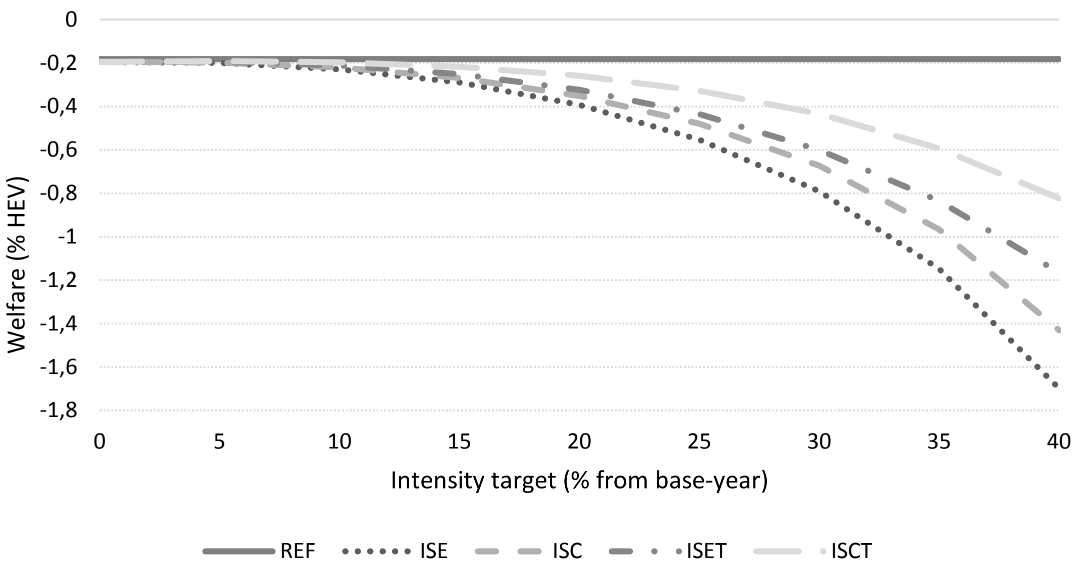
We finally turn to the discussion of economic efficiency. In principle, standards on EITE industries can constitute a second-best instrument to improve the economic efficiency of unilateral climate policy action as compared to economy-wide emission pricing. The output subsidies implicit to standards can dampen counterproductive emission leakage; however – pending on the design of the standards policy – there is also a substantial risk of creating excess cost.

Figure 5 highlights the scope for efficiency pitfalls of standards. As is customary, we measure economic efficiency in terms of Hicksian equivalent variation in income for the representative US household.[7] Figure 5 indicates that none of the four designs for standards provides efficiency advantages compared to the *REF* policy of uniform CO_2 emission pricing. To the opposite: We see that efficiency standards for EITE industries bear the risk of substantial economic excess cost as compared to economy-wide emission pricing stand-alone. When the stringency of intensity standards is set at the ambition level of emission reduction (20%), the

[7] Hicksian equivalent variation in income denotes the amount of money that is necessary to add to, or deduct, from the benchmark income of the representative household so that she enjoys a utility level equal to the one in the counterfactual policy scenario, on the basis of ex-ante prices.

excess cost of standards range between 40% and 115% of the reference policy cost. Excess cost get magnified to 3.5 times up to even more than 8 times of the reference policy cost as the mandated efficiency improvements go up to 40%. The efficiency ranking of alternative standards design reflects basic economic intuition: The less targeted the metric and the less flexible the compliance scheme across sectors, the higher the excess cost. The most costly design refers to energy standards which are not tradable across EITE sectors (scenario: *ISE*), the design with lowest excess cost involves carbon standards that are tradable across EITE sectors (scenario: *ISCT*). Note that our numerical framework incorporates initial tax distortions as provided in the GTAP database (factor taxes, intermediate input taxes, production taxes and subsidies, value-added taxes, import tariffs, export duties). In our simulation results, we do not find evidence for economic efficiency advantages of standards compared to explicit emission pricing rooted in more complex second-best tax interaction effects.

Figure 5. US welfare impacts (% Hicksian equivalent variation (HEV) in income)



The main insights from the central case simulations can be summarized as follows: For the US intensity standards for EITE sectors as a substitute for explicit emission pricing have only limited potential to reduce carbon leakage. If standards are defined at rather strict levels, they might rather increase than decrease carbon leakage as compared to economy-wide emission pricing. In the same vein, standards – if set at sufficiently lax levels – reduce the competitiveness and output losses of EITE industries compared to emission pricing but with stringency levels set at an ambition level of the overall CO_2 emission reduction target or beyond they can lead to substantial higher output losses. While the repercussions of lax standards for the output performance of the non-EITE industries are relatively modest (not at last because they represent by far a larger share of economic activity), stringent standards have also adverse impacts for non-EITE industries which reflects the bad overall economic efficiency performance of standards. Standards – in particular if levied on energy and imposed at the sector-level without flexibility – can induce substantial macroeconomic excess cost as compared to economy-wide uniform emission pricing.

4.2.2 Sensitivity analysis

To test the robustness of our results, we have performed a series of sensitivity analysis varying the target level of unilateral emission reduction target, the degree of product heterogeneity (Armington elasticities) in EITE trade, and the responsiveness of international fuel markets (fossil fuel supply elasticities). Results of the sensitivity analysis are presented in Table 3 for carbon leakage and welfare. The central case parameterization underlying our core simulation results is labeled *core* while labels *half* and *double* refer to halving or doubling of the central case parameter values.

Table 3. Sensitivity analysis – carbon leakage and US welfare

Leakage (%)														
		REF	*ISE*			*ISC*			*ISET*			*ISCT*		
Intensity target			0	20	40	0	20	40	0	20	40	0	20	40
	10	3.66	2.63	6.14	14.33	2.65	4.75	11.15	2.64	4.58	8.98	2.66	5.05	9.96
Target	20 (*central*)	4.53	3.30	4.78	8.93	3.32	4.12	7.24	3.32	4.01	5.99	3.33	4.34	6.68
	30	5.60	4.19	4.89	7.40	4.20	4.49	6.31	4.21	4.39	5.40	4.21	4.69	6.01
	half	3.86	3.12	4.20	6.17	3.14	3.58	4.76	3.13	3.55	4.02	3.14	3.95	5.21
Sigma	*central*	4.53	3.30	4.78	8.93	3.32	4.12	7.24	3.32	4.01	5.99	3.33	4.34	6.68
	double	5.49	3.53	5.61	13.22	3.55	4.90	11.25	3.55	4.65	9.05	3.56	4.89	9.16
	half	7.19	5.73	7.78	11.94	5.76	6.84	9.88	5.75	6.78	8.66	5.77	7.16	9.80
Eta	*central*	4.53	3.30	4.78	8.93	3.32	4.12	7.24	3.32	4.01	5.99	3.33	4.34	6.68
	double	2.92	1.89	2.90	6.96	1.89	2.47	5.60	1.89	2.32	4.33	1.90	2.59	4.66
Welfare (% Hicksian equivalent variation in income)														
		REF	*ISE*			*ISC*			*ISET*			*ISCT*		
Intensity target			0	20	40	0	20	40	0	20	40	0	20	40
	10	-0.04	-0.05	-0.29	-1.64	-0.05	-0.24	-1.36	-0.05	-0.22	-1.10	-0.05	-0.14	-0.74
Target	20 (*central*)	-0.18	-0.20	-0.39	-1.70	-0.19	-0.35	-1.43	-0.20	-0.32	-1.17	-0.19	-0.26	-0.82
	30	-0.49	-0.53	-0.65	-1.87	-0.53	-0.61	-1.62	-0.53	-0.58	-1.34	-0.53	-0.54	-1.04
	half	-0.16	-0.19	-0.37	-1.64	-0.19	-0.33	-1.39	-0.19	-0.30	-1.12	-0.19	-0.24	-0.79
Sigma	*central*	-0.18	-0.20	-0.39	-1.70	-0.19	-0.35	-1.43	-0.20	-0.32	-1.17	-0.19	-0.26	-0.82
	double	-0.21	-0.20	-0.42	-1.72	-0.20	-0.37	-1.44	-0.20	-0.34	-1.20	-0.20	-0.27	-0.84
	half	-0.17	-0.19	-0.38	-1.69	-0.19	-0.34	-1.42	-0.19	-0.32	-1.16	-0.19	-0.25	-0.81
Eta	*central*	-0.18	-0.20	-0.39	-1.70	-0.19	-0.35	-1.43	-0.20	-0.32	-1.17	-0.19	-0.26	-0.82
	double	-0.19	-0.20	-0.40	-1.71	-0.20	-0.36	-1.44	-0.20	-0.33	-1.17	-0.20	-0.27	-0.84

We first focus on the implications for the *REF* scenario with economy-wide emission pricing. More stringent unilateral emission reduction targets (labeled *Target* in Table 3) trigger higher unilateral emission prices and thereby lead to higher carbon leakage rates as well as higher adjustment cost for the US economy. Armington elasticities (labeled *Sigma* in Table 3) are a key driver for leakage through the trade channel: The lower the Armington elasticities are, the easier it is for foreign countries to switch away from more expensive US export goods (likewise US consumers can more easily substitute domestic products with imports) and the higher – ceteris paribus – leakage will get. Higher substitutability in turn implies reduced economic adjustment cost to unilateral emission constraints. Fossil fuel supply elasticities (labeled *Eta* in Table 3) are a key driver for leakage through the fossil-fuel market channel: The lower the supply elasticities are, the more pronounced is the drop in international fuel prices triggered by unilateral emission reduction and the higher leakage becomes. As a net importer of fossil fuels, the US will benefit from lower international fuel prices.

Regarding the impacts of intensity standards, all of our insights from the central case simulations remain robust. For unilateral US climate policy, the potential of intensity standards to reduce leakage remains limited while more stringent standards for EITE industries bear the risk of substantial welfare losses and even higher leakage rates as compared to economy-wide emission pricing.

5. CONCLUSIONS

Intensity standards have gained substantial momentum as a regulatory instrument in domestic climate policy in the US. Energy-intensive and trade-exposed industries which are particularly vulnerable to emission regulation prefer standards over explicit emission pricing since regulatory rents are kept within firms as an implicit output subsidies. Even green policy makers might embrace standards from a political economy perspective as an instrument to lower stiff resistance of influential energy-intensive industries. Under economic efficiency considerations, emission leakage provides a theoretical second-best argument for standards if a country goes ahead with emission regulation while major trading partners do not follow suit. In this paper we have used a large-scale multi-sector multi-region computable general equilibrium model of global trade and energy use to investigate the efficiency rationale of standards for the case of unilateral US climate policy. Our simulation results based on empirical data provide evidence against the use of standards from an efficiency point of view. Unilateral action by the US does not cause substantial leakage. Thus, the case of counterproductive international spillover effects that would justify standards as a second-best instrument is not a particularly strong one to start with for the US. In this vein, the potential of standards to reduce leakage and negative output effects for emission-intensive and trade-exposed industries is limited. To the opposite: Policy makers as well as emission-intensive and trade-exposed industries should be aware that more stringent standards can increase rather than decrease leakage and output losses as compared to economy-wide emission pricing. The weak case of an initial second-best environment for the US are reflected in the inferior economic efficiency performance of standards compared to economy-wide explicit emission pricing via taxes or allowances. In particular, if standards are defined on energy instead of carbon and cannot be traded across industries, there is the potential for huge excess cost as compared to economy-wide emission pricing for all segments of the economy. We conclude that the use of standards in US climate policy should be mostly justified through political economy considerations – yet, if not properly designed they may come at high cost for the overall society so policy makers might be well-advised to seek for alternative cheaper policy instruments in order to match political economy constraints.

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Appendix: Algebraic Summary of the Computable General Equilibrium Model

The computable general equilibrium model is formulated as a system of nonlinear inequalities. The inequalities correspond to the two classes of conditions associated with a general equilibrium: (i) exhaustion of product (zero profit) conditions for producers with constant returns to scale; and (ii) market clearance for all goods and factors. The former class determines activity levels, and the latter determines price levels. In equilibrium, each variable is linked to one inequality condition: an activity level to an exhaustion of product constraint and a commodity price to a market clearance condition.

In our algebraic exposition, the notation Π_{ir}^{z} is used to denote the unit profit function (calculated as the difference between unit revenue and unit cost) for production with constant returns to scale of sector *i* in region *r*, where *z* is the name assigned to the associated production activity. Differentiating the unit profit function with respect to input and output prices provides compensated demand and supply coefficients (Hotelling's lemma), which appear subsequently in the market clearance conditions. We use *g* as an index comprising all sectors/commodities *i* (*g=i*), the final consumption composite (*g=C*), the public good composite (*g=G*), and investment composite (*g=I*). The index *r* (aliased with *s*) denotes regions. The index *EG* represents the subset of energy goods coal, oil, gas, electricity, and the label *FF* denotes the subset of fossil fuels coal, oil, gas. Tables B1–B6 explain the notations for variables and parameters employed within our algebraic exposition. Figures B1–B3 provide a graphical exposition of the production structure. Numerically, the model is implemented in GAMS (Brooke et al. 1996)[8] and solved using PATH (Dirkse and Ferris 1995)[9].

Zero Profit Conditions:

1. Production of goods except fossil fuels ($g \notin FF$):

$$\Pi_{gr}^{Y} = p_{gr} - \left[\theta_{gr}^{M} p_{gr}^{M(1-\sigma_{gr}^{KLEM})} + \left(1-\theta_{gr}^{M}\right)\left[\theta_{gr}^{E} p_{gr}^{E\,(1-\sigma_{gr}^{KLE})} + \left(1-\theta_{gr}^{E}\right) p_{gr}^{KL(1-\sigma_{gr}^{KLE})}\right]^{(1-\sigma_{gr}^{KLEM})/(1-\sigma_{gr}^{KLE})}\right]^{1/(1-\sigma_{gr}^{KLEM})} \le 0.$$

2. Sector-specific material aggregate:

$$\Pi_{gr}^{M} = p_{gr}^{M} - \left[\sum_{i \notin EG} \theta_{igr}^{MN} p_{igr}^{A\;1-\sigma_{gr}^{M}}\right]^{1/(1-\sigma_{gr}^{M})} \le 0.$$

[8] Brooke, A., D. Kendrick, and Meeraus, A. (1996). GAMS: A User's Guide. GAMS Development Corporation: Washington DC.
[9] Dirkse, S., and M. Ferris (1995). The PATH Solver: A Non-monotone Stabilization Scheme for Mixed Complementarity Problems. *Optimization Methods & Software* 5: 123–56.

3. Sector-specific energy aggregate:

$$\prod_{gr}^{E} = p_{gr}^{E} - \left[\sum_{i \in EG} \theta_{igr}^{EN} \left(p_{igr}^{A} + p_{r}^{CO_2} a_{igr}^{CO_2} \right)^{1-\sigma_{gr}^{E}} \right]^{1/(1-\sigma_{gr}^{E})} \leq 0.$$

4. Sector-specific value-added aggregate:

$$\Pi_{gr}^{KL} = p_{gr}^{KL} - \left[\theta_{gr}^{K} v^{(1-\sigma_{gr}^{KL})} + \left(1-\theta_{gr}^{K}\right) w^{(1-\sigma_{gr}^{KL})} \right]^{1/(1-\sigma_{gr}^{KL})} \leq 0.$$

5. Production of fossil fuels ($g \in FF$):

$$\prod_{gr}^{Y} = p_{gr} - \left[\theta_{gr}^{Q} q_{gr}^{1-\sigma_{gr}^{Q}} + (1-\theta_{gr}^{Q}) \left(\theta_{gr}^{L} w_r + \theta_{gr}^{K} v_r + \sum_{i \notin FF} \theta_{igr}^{FF} p_{igr}^{A} \right)^{1-\sigma_{gr}^{Q}} \right]^{1/(1-\sigma_{gr}^{Q})} \leq 0.$$

6. Armington aggregate:

$$\prod_{igr}^{A} = p_{igr}^{A} - \left(\theta_{igr}^{A} p_{ir}^{1-\sigma_{ir}^{A}} + (1-\theta_{igr}^{A}) p_{ir}^{IM^{1-\sigma_{ir}^{A}}} \right)^{1/(1-\sigma_{ir}^{A})} \leq 0.$$

7. Aggregate imports across import regions:

$$\prod_{ir}^{IM} = p_{ir}^{IM} - \left[\sum_{s} \theta_{isr}^{IM} \left(p_{is} \right)^{1-\sigma_{ir}^{IM}} \right]^{1/(1-\sigma_{ir}^{IM})} \leq 0.$$

Market Clearance Conditions:

8. Labor:

$$\overline{L}_r \geq \sum_{g} Y_{gr}^{KL} \frac{\partial \Pi_{gr}^{KL}}{\partial w_r}.$$

9. Capital:

$$\overline{K}_{gr} \geq Y_{gr}^{KL} \frac{\partial \Pi_{gr}^{KL}}{\partial v_{gr}}.$$

10. Fossil fuel resources ($g \in FF$):

$$\overline{Q}_{gr} \geq Y_{gr} \frac{\partial \Pi_{gr}^{Y}}{\partial q_{gr}}.$$

11. Material composite:

$$M_{gr} \geq Y_{gr} \frac{\partial \Pi_{gr}^{Y}}{\partial p_{gr}^{M}}.$$

12. Energy composite:

$$E_{gr} \geq Y_{gr} \frac{\partial \Pi_{gr}^{Y}}{\partial p_{gr}^{E}}.$$

13. Value-added composite:

$$KL_{gr} \geq Y_{gr} \frac{\partial \Pi_{gr}^{Y}}{\partial p_{gr}^{KL}} .$$

14. Import composite:

$$IM_{ir} \geq \sum_{g} A_{igr} \frac{\partial \Pi_{igr}^{A}}{\partial p_{ir}^{IM}} .$$

15. Armington aggregate:

$$A_{igr} = Y_{gr} \frac{\partial \Pi_{gr}^{Y}}{\partial p_{igr}^{A}} .$$

16. Commodities (*g*=*i*):

$$Y_{ir} \geq \sum_{g} A_{igr} \frac{\partial \Pi_{igr}^{A}}{\partial p_{ir}} + \sum_{s \neq r} IM_{is} \frac{\partial \Pi_{is}^{IM}}{\partial p_{ir}} .$$

17. Private consumption composite (*g*=*C*):

$$Y_{Cr} p_{Cr} \geq w_r \overline{L}_r + \sum_{g} v_{gr} \overline{K}_{gr} + \sum_{i \in FF} q_{ir} \overline{Q}_{ir} + p_r^{CO_2} \overline{CO}_{2r} + \overline{B}_r .$$

18. Public consumption composite (*g*=*G*):

$$Y_{Gr} \geq \overline{G}_r .$$

19. Investment composite (*g*=*I*):

$$Y_{Ir} \geq \overline{I}_r .$$

20. Carbon emissions:

$$\overline{CO}_{2r} \geq \sum_{g} \sum_{i \in FF} E_{gr} \frac{\partial \Pi_{gr}^{E}}{\partial \left(p_{igr}^{A} + p_{r}^{CO_2} a_{igr}^{CO_2} \right)} a_{igr}^{CO_2} .$$

Table A1. Indices (sets)

G	Sectors and commodities (*g*=*i*), final consumption composite (*g*=*C*), public good composite (*g*=*G*), investment composite (*g*=*I*)
I	Sectors and commodities
r (alias *s*)	Regions
EG	Energy goods: coal, crude oil, refined oil, gas, and electricity
FF	Fossil fuels: coal, crude oil, and gas

Table A2. Activity Variables

Y_{gr}	Production of item *g* in region *r*
M_{gr}	Material composite for item *g* in region *r*
E_{gr}	Energy composite for item *g* in region *r*
KL_{gr}	Value-added composite for item *g* in region *r*
A_{igr}	Armington aggregate of commodity *i* for demand category (item) *g* in region *r*
IM_{ir}	Aggregate imports of commodity *i* and region *r*

Table A3. Price Variables

p_{gr}	Price of item *g* in region *r*
p^{M}_{gr}	Price of material composite for item *g* in region *r*
p^{E}_{gr}	Price of energy composite for item *g* in region *r*
p^{KL}_{gr}	Price of value-added composite for item *g* in region *r*
p^{A}_{igr}	Price of Armington good *i* for demand category (item) *g* in region *r*
p^{IM}_{ir}	Price of import composite for good *i* in region *r*
w_{r}	Price of labor (wage rate) in region *r*
v_{ir}	Price of capital services (rental rate) in sector *i* and region *r*
q_{ir}	Rent to fossil fuel resources in region *r* ($i \in$ FF)
$p^{CO_2}_{r}$	Carbon value in region *r*

Table A4. Endowments and Emissions Coefficients

$\overline{L}_r$	Aggregate labor endowment for region *r*
$\overline{K}_{ir}$	Capital endowment of sector *i* in region *r*
$\overline{Q}_{ir}$	Endowment of fossil fuel resource *i* for region *r* ($i \in$FF)
$\overline{B}_r$	Initial balance of payment deficit or surplus in region *r* (note: $\sum_r \overline{B}_r = 0$)
$\overline{CO_2}_r$	Endowment of carbon emissions rights in region *r*
$a^{CO_2}_{igr}$	Carbon emissions coefficient for fossil fuel *i* in demand category *g* of region *r* ($i \in FF$)

Table A5. Cost Shares

θ^{M}_{gr}	Cost share of the material composite in production of item *g* in region *r*
θ^{E}_{gr}	Cost share of the energy composite in the aggregate of energy and value-added of item *g* in region *r*
θ^{MN}_{igr}	Cost share of the material input *i* in the material composite of item *g* in region *r*
θ^{EN}_{igr}	Cost share of the energy input *i* in the energy composite of item *g* in region *r*
θ^{K}_{gr}	Cost share of capital within the value-added of item *g* in region *r*
θ^{Q}_{gr}	Cost share of fossil fuel resource in fossil fuel production ($g \in FF$) of region *r*
θ^{L}_{gr}	Cost share of labor in non-resource inputs to fossil fuel production ($g \in FF$) of region *r*
θ^{K}_{gr}	Cost share of capital in non-resource inputs to fossil fuel production ($g \in FF$) of region *r*
θ^{FF}_{igr}	Cost share of good *i* in non-resource inputs to fossil fuel production ($g \in FF$) of region *r*
θ^{A}_{igr}	Cost share of domestic output *i* within the Armington item *g* of region *r*
θ^{M}_{isr}	Cost share of exports of good *i* from region *s* in the import composite of good *i* in region *r*

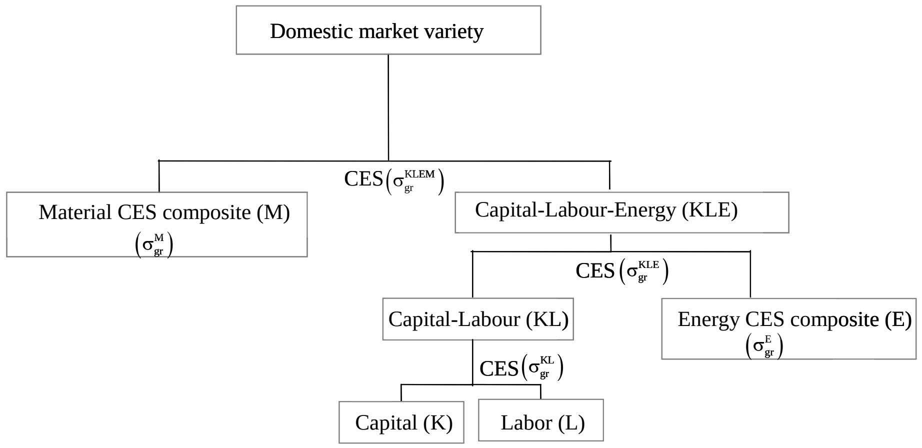
Table A6. Elasticities

σ^{KLEM}_{gr}	Substitution between the material composite and the energy value–added aggregate in the production of item *g* in region *r*[*]
σ^{KLE}_{gr}	Substitution between energy and the value-added nest of production of item *g* in region *r*[*]
σ^{M}_{gr}	Substitution between material inputs within the energy composite in the production of item *g* in region *r*[*]
σ^{KL}_{gr}	Substitution between capital and labor within the value-added composite in the production of item *g* in region *r*[*]
σ^{E}_{gr}	Substitution between energy inputs within the energy composite in the production of item *g* in region *r* (by default: 0.5)
σ^{Q}_{gr}	Substitution between natural resource input and the composite of other inputs in fossil fuel production ($g \in$ FF) of region *r* (calibrated consistently to exogenous supply elasticities)
σ^{A}_{ir}	Substitution between the import composite and the domestic input to Armington production of good *i* in region *r*[**]
σ^{IM}_{ir}	Substitution between imports from different regions within the import composite for good *i* in region *r*[**]

*See Okagawa, A., and K. Ban. 2008. Estimation of Substitution Elasticities for CGE Models. Mimeo. Osaka, Japan: Osaka University.

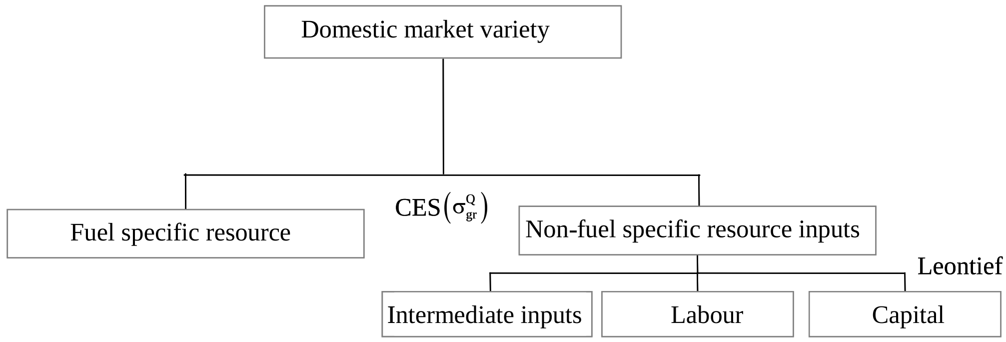
**See Narayanan, G.,B., Aguiar, A., and Robert McDougall, Eds. 2015. Global Trade, Assistance, and Production: The GTAP 9 Data Base, Center for Global Trade Analysis, Purdue University.

Figure A1. Nesting in Production (Except Fossil Fuels)



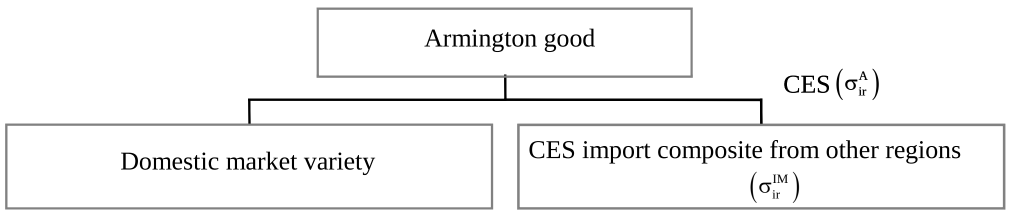
Note: CES=constant elasticity of substitution.

Figure A2. Nesting in Fossil Fuel Production



Note: CES=constant elasticity of substitution.

Figure A3. Nesting in Armington Production



Note: CES=constant elasticity of substitution.

Zuletzt erschienen /previous publications:

V-384-15 **Christoph Böhringer, Xaquín Garcia-Muros, Mikel Gonzalez-Eguino, Luis Rey,** US Climate Policy: A Critical Assessment of Intensity Standards
V-383-15 **Christoph Böhringer, Edward J. Balistreri, Thomas F. Rutherford**, Carbon policy and the structure of global trade
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