Foreign Climate Policy and Domestic Industry Adjustment in a Small Open Economy

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Abstract

Amid weak international cooperation a significant stretch of the climate policy efforts will continue to take the form of unilateral policies. However, concerns about the competitiveness and the risk of carbon leakage limit the scope and acceptability of carbon pricing on domestic production. In this context, Border Carbon Adjustments (BCA) have gained prominence as a complement to carbon taxes. Using a trade adjustment dynamics model we investigate if, from the perspective of a small open economy (SOE), the credible implementation of a BCAs by a climate conscious coalition provides incentives for the early implementation of domestic climate policy. In particular, if the early implementation of climate policy by the SOE serves to reduce the exposure to the future implementation of BCAs by trading partners. Using the data for the Colombian economy, our results indicate that the scope for domestic climate policy is affected by whether the BCA design prescribes a tariff hike that adjusts with the emissions of the targeted sector.

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*The views expressed in this paper are solely those of the authors and should not be thought of as representing the views of the Central Bank of Colombia.

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1 Introduction

Meeting climate targets will require the implementation of stricter climate polices in the near future. Amid weak international cooperation a significant portion of the needed effort will continue to take the form of unilateral policies. In this context, unilateral carbon pricing schemes, in particular carbon taxes, are considered an essential element of the policy toolkit to mitigate climate change.

However, the implementation of unilateral carbon pricing schemes suffers from some challenges. A prominent argument against the political viability of ambitious unilateral schemes is the loss of competitiveness of domestic industries relative to competing industries from countries with less comprehensive, environmental regulation (e.g., Dechezleprêtre & Sato, 2017; Demailly & Quirion, 2006). A related argument is that as consequence of strict unilateral policies production and consumption may shift to jurisdictions with more lax regulations, resulting in emissions leakage, which will ultimately undermine the effectiveness of unilateral policies (e.g., Babiker, 2005; Dröge et al., 2009; Levinson & Taylor, 2008).

With these concerns in the background, Border Carbon Adjustments (BCAs) have gained prominence as potential complements to unilateral carbon pricing schemes on domestic production.[1] First, BCAs can level the playing field for the domestic industries, in particular the Energy-Intensive and Trade-Exposed industries (EITE) (Branger & Quirion, 2014a): the introduction of BCAs closes the carbon pricing gap between domestic firms subject to unilateral schemes, and their foreign competitors. Second, the implementation of BCAs implies that firms that operate in jurisdictions subject to carbon pricing have lower incentives to relocate their operations, which reduces the risk of carbon leakage (Branger & Quirion, 2014b; Fischer & Fox, 2012; IMF/OECD, 2021): closing the carbon pricing gap implies that, in terms of averted payments for emissions, there is no advantage in relocating production to a foreign location for a firm that will still serve the domestic market. Next to these direct benefits, BCAs can generate incentives for other countries to implement climate policy of their own in order to reduce the exposure of their exports to carbon based tariffs by their trading partners (Helm, Hepburn, & Ruta, 2012).

Based on these potential benefits, and in light of the limited progress on coordinated global climate action, BCAs are gaining attention in policy circles as part of unilateral climate

[1] See Cosbey, Droege, Fischer, and Munnings (2019) for a comprehensive review on BCAs.

initiatives. The EU has already announced the introduction of the Carbon Border Adjustment Mechanism (CBAM) which is expected to be fully operational in 2026. The EU CBAM is intended to initially target the imports of 5 sectors considered to have a high risk of carbon leakage and a high level of emissions: cement, iron and steel, aluminum, fertilizers, and electricity. Upon an initial revision stage the scheme may be extended to other relevant sectors (European Commission, 2021). Besides the EU initiative, other advanced economies like the US, Canada, and Japan are firmly considering the implementation of BCAs.

Hence, the implementation of comprehensive BCAs seems to be more a matter of 'when' not 'if'. In this context, what does the potential implementation of a BCA by a country or a 'climate conscious' coalition of countries imply for its trading partners? In principle, this constitutes a transitional risk, and this may be particularly salient for small open economies with incipient climate policy and highly exposed exports. That is, countries with a high share of carbon intensive exports to regions likely to end up implementing carbon-based tariffs in the near future. This begs the question of what an economy can do to hedge the inevitability of foreign carbon tariffs, and if this transition risk creates enough incentives for an earlier implementation or tightening of climate mitigation policy in the exposed economies. Such course of action may be justified by the impact of current domestic climate policy on the future composition of the domestic industry and its exposure to the foreign carbon tariff risk; however, it comes at a cost to the extent that it implies a relocation of factors from dirtier to cleaner sectors.

Understanding the trade-off between transitional risk mitigation and the cost of sectoral relocation is crucial to determine whether BCAs indeed have the potential to spur climate action in other countries, and ultimately serve as a coordination device for climate policy. We study this question from the perspective of a small open economy (SOE) facing the impending implementation of a BCA by a subset of its trading partners.

We put forward a model of trade adjustment dynamics featuring three economies: the SOE, and two 'rest of the world' (ROW) regions. One of the ROW regions constitutes a 'climate conscious' coalition, with climate policy of its own and the intention to implement a BCA. The three economies interact through trade in three markets, a clean intermediate good, a dirty (i.e., carbon-intensive) intermediate good, and fossil energy. Domestically produced and imported intermediates are used for the production of final non-tradable consumption and investment goods. Two intermediate goods, clean and dirty, are produced using multiple varieties of domestic and foreign inputs. In turn, these inputs are produced by firms with heterogeneous productivity using capital, materials, labor and fossil energy. Inputs used by the dirty intermediate sector are more fossil energy-intensive (i.e., more carbon-intensive) than the inputs used by the clean sector. Firms producing carbon-intensive inputs are exposed to the implementation of carbon tariffs by the climate conscious coalition. Thus, the dirty input producing sector is meant to reflect the aggregation of sectors being potentially targeted by BCAs. We introduce firm and trade dynamics in our model by assuming that input producers face different fixed and variable costs depending on the export tenure. This produces a slower aggregate response of production and exports, which is consistent with empirical regularities (Ruhl & Willis, 2017).

Using this framework we first explore the effect on the SOE of an anticipated introduction of a BCA by the climate conscious coalition. We focus on output and trade dynamics at the aggregate and sectoral levels as well as on the level of aggregate consumption. Then, we investigate if this anticipated introduction of a BCA justifies that the SOE implements (more stringent) domestic carbon taxation, even if climate/environmental concerns are fully disregarded. In particular, we quantitatively assess if an earlier tightening of domestic carbon pricing by the SOE can serve to mitigate losses associated to future foreign carbon tariffs, and if the benefits associated to averting those future losses justifies the cost of tightening climate policy.

For this quantitative assessment we calibrate our model to the Colombian economy, which currently has a relatively low carbon tax and is exposed to the BCA implementation by the EU. The calibration uses aggregate and firm level data for the 2010-2019 period. In particular, we use national accounts and input-output information to match some sectoral moments, and the manufacturing census to match firm sectoral dynamics.

Our results indicate that the introduction of a BCA by a coalition of its trading partners, is detrimental for the SOE. In the absence of any policy adjustment by the SOE, the introduction of a BCA that increases by 10% the tariffs faced by the producers of the dirty sector exporting to the climate conscious coalition results in a reduction of 1% in aggregate consumption in the long-run. The most significant impact is on aggregate real exports, clean and dirty, which overall decline by 15%. Aggregate gross output and investment barely decline.

These aggregate effects respond to the sectoral dynamics unraveled by the BCA announcement and implementation. The BCA causes a contraction of the domestic dirty sector which is accompanied by an expansion of the clean sector. However, firm and trade dynamics warrant a sluggish response by the clean sector, and in turn this implies that the short-run contraction of aggregate variables in general overshoot the long-term response. This underscores the relevance of analyzing the dynamic impact. If the SOE tightens its carbon pricing upon the BCA announcement in anticipation to its implementation, little changes in terms of aggregate effects, but the sectoral responses are exacerbated. That is, the dirty sector contracts even more and the clean sector expands. These results would indicate that there is little justification for the implementation of early climate policy to counter the effects of a BCA.

We then study the effects of an alternative BCA design, where instead of a flat tariff increase, the tariff hike faced by the dirty sector adjusts proportionally to changes in the sector-wide fossil energy use. Under this 'conditional' BCA the aggregate and sectoral responses are qualitatively similar to those under the flat BCA, although somewhat milder. Interestingly, the BCA design is relevant for the effect of implementing early climate policy in the SOE. Specifically, an early climate policy implementation will partially revert the sectoral effects of the BCA, and the losses of the dirty sector will be ameliorated. Thus, in case of a conditional BCA there may be scope for the implementation of early domestic policy in the SOE on the grounds of sectoral redistribution.

Our paper relates to the literature on the implementation of tariffs based on carbon contents. This literature is built on the argument that, in the absence of global cooperation, unilateral carbon pricing schemes by can be efficiently supplemented by carbon tariffs on imports from countries with less stringent climate policy (Hémous, 2016; Hoel, 1996; Markusen, 1975; van der Ploeg, 2016). As these tariffs are part of a second-best policy menu, contributions in this literature concentrate on the efficiency of alternative tariff schemes and asserting their effectiveness in reducing carbon-leakage (e.g., Balistreri & Rutherford, 2012; Balistreri, Böhringer, & Rutherford, 2018; Böhringer, Bye, Fæhn, & Rosendahl, 2012; Larch & Wanner, 2017). This is done by comparing outcomes of static equilibriums under different tariff configurations.

This literature focuses on the rationalization of an eventual implementation of 'carbon tariffs' by members of an abating coalition with uniform carbon pricing. Instead of adopting a global welfare perspective and evaluating the merits of different tariff designs, we study the effects that the risk of implementation of such tariffs on their trading partners. Specifically, we examine the scope for a SOE to preemptively engage in climate policy of its own, as an strategy to mitigate the loss in competitiveness caused by the eventual implementation of the tariffs in the destinations of its exports.

In a related study, Böhringer, Carbone, and Rutherford (2016) find that the (credible threat of) implementation of carbon tariffs by countries in an abating coalition can prompt abatement efforts by non-coalition regions. This result is based on the comparison of payoffs emerging from static general equilibriums across the action space of coalition and non-coalition regions. In contrast, our analysis emphasizes the dynamic response of the domestic industry to the risk of foreign carbon tariffs and their eventual implementation, as well as to the potential implementation of domestic climate policy. We are particularly interested in capturing how domestic climate policy can contribute to the graduality of the adjustment of the domestic industry to the risk and eventual implementation of foreign tariffs. For this, we adopt a dynamic trade model with industry adjustments. As in Balistreri and Rutherford (2012) and Balistreri et al. (2018) we rely on a model with heterogeneous firms to capture the differential impact of BCAs across sectors and between exporters and non-exporters. However, our framework incorporates firm and trade dynamics and thus is suited to capture the transitional effects triggered by the foreign and domestic policy changes. As such, we are in a unique position to identify the immediate and long-run impacts on a SOE of a BCA implementation by trading partners, as well as to capture the differences between immediate and delayed policy responses.

The rest of the paper is organized in five sections. Section 2 describes the firm and trade dynamics setup we use to study the question at hand. Section 3 introduces the data and calibration strategy. Section 4 presents and discusses the quantitative effects on the SOE of four distinct scenarios: two alternative BCA designs, flat and 'conditional', with and without climate policy response by the SOE. Section 5 focuses on the welfare implications for the SOE of each of these scenarios. Section 6 presents the concluding remarks.

2 Model

To study the question at hand we put forward a three-economies two-sector model of trade adjustment dynamics. The model consists of three countries that differ in size, given by the endowment of labor and fossil resource (maximum extraction flow), have different technologies, as captured by differences in fixed and variable costs of production and export, and uneven climate policies. The domestic economy, which is the focus of our analysis, is a small open economy denoted as SOE, the 'rest of the world' is divided in two economies denoted as ROW_1 and ROW_2, where the former is a 'climate conscious' coalition of countries (e.g., EU) that announces the unilateral implementation of a BCA. The three economies operate under financial autarky, meaning that total exports equal total imports (balanced trade).

2.1 Production structure: Overview

The production structure in the three economies is the same and is characterized by four layers: final goods and materials, intermediate goods, inputs, fossil energy.

i. Final goods and materials A consumption good, investment goods, and materials are produced competitively by combining two intermediate goods: clean and dirty.

ii. Intermediate goods: clean and dirty There are two sectors of intermediate goods, each competitively producing an intermediate. The production of each of the two intermediate goods uses multiple varieties of domestic and foreign inputs. These input varieties are specific to the production of a given intermediate, i.e., inputs are sector-specific.

iii. Inputs Heterogeneous firms operating in monopolistic competition produce sector-specific inputs; in each economy there is a mass of firms producing clean inputs, used in the production of the clean intermediate, and a mass of firms producing dirty inputs, used in the production of the dirty intermediate. These input producers use specific (i.e., clean or dirty) capital and materials, as well as homogeneous labor and fossil energy. The fundamental distinction between clean and dirty input producers is that the latter have a more energy-intensive technology.

Input producers need to pay fixed costs to enter, produce, and export. The entry decision occurs prior to firms knowing their own productivity and is hence based on whether the expected discounted value of doing so is positive. Once a firm enters the idiosyncratic productivity is revealed. With this information a firm decides whether to produce and to export in a given period. Active firms decide how much capital, labor, materials and fossil energy to use. To account for learning experience in the international markets, the model distinguishes between new and incumbent exporters, where the latter pay lower fixed and variable export costs. Variable export costs include iceberg costs and sector-specific tariffs. These tariffs are the central element of the policy experiments in our setting, as they constitute the instrument through which BCAs are operationalized.

iv. Fossil energy Fossil energy, used in the production of sector-specific inputs, is produced by combining labor, energy-specific capital, and fossil resources. The supply of fossil resources is an exogenous endowment which, rather than standing for the stock of resources, represents the maximum rate at which fossil resources can flow into the production of energy in each economy.

2.2 Setup

2.2.1 Households

In a given economy $i \in \{SOE,\, ROW_1,\, ROW_2\}$ consumers maximize the present value of their utility by choosing the paths of consumption and sector-specific investment

$$\max_{\{C_{i,t},K^{s+}_{t+1}\}_{t=0}^{\infty}} E_t \sum_{t=0}^{\infty} \beta^t U(C_{i,t}),$$

with $s+ \in \{clean,\, dirty,\, energy\}$, subject to the budget constraint

$$P^c_{i,t}C_{i,t} + \sum_{s+} P^{K_{s+}}_{i,t} I^{s+}_{i,t} = W_{i,t}L_i + P^{z,e}_{i,t} Z^e_i + \sum_{s+} \left(R^{s+}_{i,t} K^{s+}_{i,t}\right) + \Pi_{i,t} + T_{i,t}, \tag{1}$$

and the laws of motion of the sectoral capital stocks, which feature adjustment costs

$$K^{s+}_{i,t+1} = I^{s+}_{i,t} + \phi^{s+}_k \left(\frac{I^{s+}_{i,t}}{I^{s+}_{i,t-1}} - 1\right)^2 - (1-\delta^{s+})K^{s+}_{i,t}. \tag{2}$$

From the first order conditions of this problem (FOC) we obtain the standard maximizing conditions for investment,

$$U'(C_{i,t})\frac{P^{K_{s+}}_t}{P^c_{i,t}} = \mu^{s+}_{i,t}\left(1 - \phi^{s+}_k \left(\frac{I^{s+}_{i,t}}{I^{s+}_{i,t-1}} - 1\right)\frac{1}{I^{s+}_{i,t-1}}\right) + \beta\mu^{s+}_{i,t+1}\phi^{s+}_k\left(\frac{I^{s+}_{i,t+1}}{I^{s+}_{i,t}} - 1\right)\frac{I^{s+}_{i,t+1}}{(I^{s+}_{i,t})^2},$$

and capital

$$\mu_{i,t}^{s+} = \beta E_t U'(C_{i,t+1}) \frac{R_{i,t+1}^{s+}}{P_{i,t+1}^{c}} + \mu_{i,t+1}^{s+}(1-\delta^{s+});$$

where $\mu_{i,t}^{s+}$ is the Lagrange multiplier associated to law of motion of capital in sector $s+$.

2.2.2 Production of final goods (consumption and investment) and materials

Consumption and investment goods and materials are produced using constant elasticity of substitution (CES) technologies that combine intermediates from the two intermediate sectors s: clean and dirty. These technologies are specific for consumption, materials, and investment goods. In all cases, the representative firm operates in perfect competition and is profit maximizing.[2] The production of the consumption good is determined by the solution to

$$\max_{X_i^{c,s}} P_i^c C_i - \sum_s P_i^s X_i^{c,s},$$

subject to

$$C_i = \left(\sum_s \left(\omega_i^{c,s}\right)^{\frac{1}{\theta}} \left(X_i^{c,s}\right)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}},$$

where $X_i^{c,s}$ is the quantity of the intermediate $s \in \{clean,\, dirty\}$ used to produce the consumption good. From the FOC we obtain the demand for intermediates as a function of sector prices, $X_i^{c,s} = \omega_i^{c,s} \left(P_i^s\right)^{-\theta} \left(P_i^c\right)^{\theta-1} D_i^c$, where $D_i^c = P_i^c C_i$ denotes the total nominal expenditure on consumption. From the problem above we also obtain the consumption price $P_i^c = \left(\sum_s \omega_i^{c,s}(P_i^s)^{1-\theta}\right)^{\frac{1}{1-\theta}}$.

Similarly, the production of sector(clean/dirty)-specific materials follows from solving

$$\max_{X_i^{M_s,s}} P_i^{M_s} M_i^s - \sum_{s'} P_{i,t}^{s'} X_i^{M_s,s'},$$

subject to

$$M_{i,t}^s = \left(\sum_{s'} \left(\lambda_i^{M_{s,s'}}\right)^{\frac{1}{\sigma_{m,s}}} \left(X_{i,t}^{M_{s,s'}}\right)^{\frac{\sigma_{m,s}-1}{\sigma_{m,s}}} \right)^{\frac{\sigma_{m,s}}{\sigma_{m,s}-1}},$$

where $X_i^{M_{s,s'}}$ are the intermediates from sector $s' \in \{clean,\, dirty\}$ used in the production of materials for sector s. From the solution of this problem we obtain that the demand

[2] To simplify the notation we omit the time subscript.

for sector intermediates is $X_i^{M_{s,s'}} = \lambda_i^{M_{s,s'}} \left(\frac{P_i^{M_s}}{P_i^{s'}}\right)^{\sigma_m} \frac{D_i^{M_s}}{P_i^{M_s}}$, where $D_i^{M_s} = P_i^{M_s} M_i^{M_s}$ is the total nominal expenditure of sector s on material, and the price of these materials is $P_i^{M_s} = \left(\sum_{s'} \lambda_{s'}^{i,M_s} (P_{s'}^i)^{1-\sigma_{m,s}}\right)^{1/1-\sigma_{m,s}}$.

Finally, the production of sector(clean/dirty/energy)-specific investment goods is given by the solution to

$$\max_{X_i^{K_{s+,s'}}} P_i^{K_{s+}} I_i^{s+} - \sum_{s'} P_{i,t}^{s'} X_i^{K_{s+,s'}},$$

subject to

$$I_{i,t}^{s+} = \left(\sum_{s'} \left(\omega_i^{K_{s+,s'}}\right)^{\frac{1}{\sigma_{s+}}} \left(X_{i,t}^{K_{s+,s'}}\right)^{\frac{\sigma_{s+}-1}{\sigma_{s+}}}\right)^{\frac{\sigma_{s+}}{\sigma_{s+}-1}},$$

where $X^{K_{s+,s'}}$ is the quantity of intermediate good $s' \in \{clean, dirty\}$ used in the production of investment goods specific to sector $s+ \in \{clean, dirty, energy\}$. From the FOCs we obtain the demand for intermediates, $X_i^{K_{s+,s'}} = \omega_i^{K_{s+,s'}} \left(\frac{P_i^{K_{s+}}}{P_i^{s'}}\right)^{\sigma_{s+}} \left(\frac{D_i^{K_{s+}}}{P_i^{K_{s+}}}\right)$, where $D_i^{K_{s+}}$ is the nominal expenditure on $s+$-specific investment goods, $D_i^{K_{s+}} = P_i^{K_{s+}} I_i^{K_{s+}}$, and the price of investment, $P_i^{K_{s+}} = \left(\sum_{s'} \omega_{s'}^{i,K_{s+}} (P_{s'}^i)^{1-\sigma_{s+}}\right)^{\frac{1}{1-\sigma_{s+}}}$.

The total demand for intermediates from sector s is given by

$$X_i^s = X_i^{c,s} + \sum_{s+} X_i^{K_{s+,s}} + \sum_{s'} X_i^{M_{s',s}}.$$

2.2.3 Production of intermediate goods

The two intermediate goods sectors, clean and dirty, are competitive. Firms in these sectors use heterogeneous varieties of domestic and imported sector-specific inputs. That is, to produce the clean (dirty) intermediate good, the representative combines domestic and imported clean (dirty) inputs. To simplify notation we will omit the time subscript. The problem of the representative firm producing intermediate s in economy i is given by the solution to

$$\max_{Y_{i,i}^s, Y_{i,j}^s} P_i^s X_i^s - \sum_{ex} \int P_{i,i}^s(a, ex) Y_{i,i}^s(a, ex)\phi(a)da - \sum_{j \neq i} \tau_{i,j}^s \sum_{ex^*} \int P_{i,j}^s(a, ex^*) Y_{i,j}^s(a, ex^*)\phi(a)da,$$

subject to

$$X_i^s = \left(\sum_j (\omega_{i,j}^s)^{\frac{1}{\theta_s}} \sum_{ex} \int \left(Y_{i,j}^s(a, ex)\right)^{\frac{\theta_s - 1}{\theta_s}} \phi(a)da\right)^{\frac{\theta_s}{\theta_s - 1}}.$$

Inputs, Y^s, are produced by heterogeneous firms that can be characterized by their idiosyncratic productivity a, export status ex. $Y^s_{i,i'}(a,.)$ denotes the use in economy i of the s-specific input a produced in economy i'; the export status ex is in one of three possible states, 'no exporter', 'new exporter', or 'old exporter'. Similarly, ex^* denotes the export status exporters from economy j selling inputs to the producers of intermediates in economy i; hence, ex^* can only take the states of 'new exporter' or 'old exporter'. From the FOC we obtain the demands for domestic and foreign heterogeneous inputs, $Y^s_{i,i}(a,ex) = \omega^s_{i,i}(P^s_{i,i}(a,ex))^{-\theta_s}(P^s_i)^{\theta_s-1}D^s_i$ and $Y^s_{i,j}(a,ex^*) = (\omega^s_{i,j})(\tau^s_{i,j}P^s_{i,j}(a,ex^*))^{-\theta_s}(P^s_i)^{\theta_s-1}D^s_i$, where $D^s_i = P^s_i X^s_i$, and the sector prices are

$$P^s_i = \left[\omega^s_{i,i}\sum_{ex}\int(P^s_{i,i}(a,ex))^{1-\theta_s}\phi(a)da + \sum_{j\neq i}\omega^s_{i,j}\sum_{ex^*}\int(\tau^s_{i,j}P^s_{i,j}(a,ex^*))^{1-\theta_s}\phi(a)da\right]^{\frac{1}{1-\theta_s}} \tag{3}$$

Finally, $\tau^s_{i,j} \geq 1$ denotes the tariffs to s-specific inputs exported from j to i. These tariffs are sector- and country-pair-specific. In our setting, a BCA translates into the unilateral increase to the tariffs on dirty inputs imports from all countries.

2.2.4 Production of sector-specific inputs

Inputs are produced by two separate sectors, each supplying a given intermediate sector. In each input producing sector, heterogeneous producers use labor, material and sector-specific capital to produce a unique variety of the sector-specific inputs. These heterogeneous firms are fully characterized by their current (iid) productivity and their prior export status. They face fixed costs to entry, produce, and export. The latter are lower for continuation exporters (i.e., those that exported in the previous period). After paying the entry fee firms draw their productivity from a $\phi(a)$ distribution, and after observing this productivity firms decide whether to produce. To keep the model tractable, we assume that firm productivity resets every period, and the new productivity is revealed before production decisions are made; nonetheless, firms only pay the entry cost once, thus incumbents do not need to pay the entry cost to learn their current productivity. To produce, firms pay a fixed production cost and use labor and capital. Incumbent firms also decide whether to export, which the can do after incurring an additional fixed costs. This fixed cost of exporting is lower for continuation exporters. Finally, firms die exogenously.

The problem of a heterogeneous input producer with productivity a is given by the solution to

$$\max_{P^s_{i,i},P^s_{j,i},ex'} P^s_{i,i}(a,ex)Y^s_{i,i}(a,ex) + ex'\sum_{j\neq i}\left(P^s_{j,i}(a,ex)Y^s_{j,i}(a,ex)-\right.$$

$$\left.\left(W_i f^s_{ex,i} + W_i l^s_i + R^s_i k^s_i + P^z z^s_i + \sum_{s'} P^{M_s}_i m^{s'}_i + W_i f^s_{p,i}\right)\right),$$

subject to

$$Y^{CD,s}_i = (k^s_i)^{\alpha^s_i}(l^s_i)^{\kappa^s_i}(m^s_i)^{1-\alpha^s_i-\kappa^s_i}, \tag{4}$$

$$Y^s_i(a) = a^{\frac{1}{\theta_s-1}}\left[(1-\omega^{y,s}_i)^{\frac{1}{\gamma^s_i}}(Y^{CD,s}_i)^{\frac{\gamma_s-1}{\gamma_s}} + (\omega^{y,s}_i)^{\frac{1}{\gamma^s_i}} z_{i,s}^{\frac{\gamma^s_i-1}{\gamma^s_i}}\right]^{\frac{\gamma^s_i}{\gamma^s_i-1}}, \tag{5}$$

and

$$Y^s_i(a,ex) = Y^s_{i,i}(a,ex) + ex'\xi^s_{ex,i,j}Y^s_{j,i}. \tag{6}$$

ex and ex' are indicators for the prior and current export status, respectively; $\xi^{s,i,j}_{ex}$ is the export iceberg cost faced by a firm from i to j with prior export status ex.

From the solution to this optimization problem we find the prices that each firm sets in the domestic and foreign markets as a function of its marginal costs, $P^s_{i,i}(a,ex) = \frac{\theta_s}{\theta_s-1}MC^s_i a^{\frac{1}{1-\theta_s}}$ and $P^s_{j,i}(a,ex) = \frac{\theta_s}{\theta_s-1}\xi^s_{ex,i}MC^s_i a^{\frac{1}{1-\theta_s}}$; with, $MC^s_i = \left((1-\omega^{y,s}_i)\left(MC^{CD,s}_i\right)^{1-\gamma^s_i} + \omega^{y,s}_i(P^z)^{1-\gamma^s_i}\right)^{\frac{1}{1-\gamma^s_i}}$, and $MC^{CD,s}_i = \left(\frac{R^s_i}{\alpha^s_i}\right)^{\alpha^s_i}\left(\frac{W_i}{1-\alpha^s_i}\right)^{\kappa^s_i}\left(\frac{P^{M_s}_i}{1-\alpha^s_i-\kappa^s_i}\right)^{1-\alpha^s_i-\kappa^s_i}$.

Productivity thresholds From the problem of an heterogeneous producer of inputs it is possible to find the productivity thresholds governing the entry, production, and export decisions. First, let us define profits before fixed costs as

$$\pi^s_i(a,ex) = \Pi^s_{0,i}a\left[(P^s_i)^{\theta_s-1}D^s_i\omega^s_{i,i} + \sum_{j\neq i} ex'(\xi^s_{ex,i,j})^{1-\theta_s}(\tau^s_{j,i})^{-\theta_s}(P^s_j)^{\theta_s-1}D^s_j\omega^s_{j,i}\right],$$

where, $\Pi^s_{0,i,m} = \frac{1}{\theta_s}\left(\frac{\theta_s}{\theta_s-1}MC^s_{i,m}\right)^{1-\theta_s}$. The marginal producer is the defined as one for which profits before fixed costs being exactly equal to the entry cost, that is $\pi^s_i(a^s_{p,i},0) = W_i f^s_{p,i}$; $a^s_{p,i}$ is the productivity threshold for the marginal producer, and is given by

$$a^s_{p,i} = \frac{W_i f^s_{p,i}}{\Pi^s_{0,i}(P^s_i)^{\theta_s-1}D^s_i\omega^s_{i,i}}. \tag{7}$$

Marginal exporter The value of an active firm is given by

$$V_s^i(ex', a, ex) = \pi_i^s(a, ex) - W_i f_{p,i}^s - ex' W_i f_{ex,i}^s + n_i Q_i EV_i^s(ex'),$$

where $Q_{i,t} = \beta E_t U'(C_{i,t+1})/U'(C_{i,t})$ is the stochastic discount factor, and $EV_i^s(ex')$ is the expected value of an exporting firm with current export status ex'. Marginal exporters are indifferent between exporting or not, meaning that $V_i^s(1, a_{ex,i}^s, ex) = V_i^s(0, a_{ex,i}^s, ex)$, where $a_{ex,i}^s$ is the productivity threshold for an exporter with past export decision ex. From this condition we obtain

$$W_i f_{0,i}^s = \sum_{j \neq i} \frac{\Pi_{0,i}^s a_{0,i}^s (\xi_{0,i,j}^s)^{1-\theta_s} D_j^s}{(\tau_{j,i}^s)^{\theta_s} (P_j^s)^{1-\theta_s} \omega_{j,i}^s} + n_i Q_i \left(EV_i^s(1) - EV_i^s(\infty) \right).$$

Similarly,

$$W_i f_{1,i}^s = \sum_{j \neq i} \frac{\Pi_{0,i}^s a_{1,i}^s (\xi_{1,i,j}^s)^{1-\theta_s} D_j^s}{(\tau_{j,i}^s)^{\theta_s} (P_j^s)^{1-\theta_s} \omega_{j,i}^s} + n_i Q_i \left(EV_i^s(1) - EV_i^s(\infty) \right).$$

To find the productivity thresholds we first must get the expected values of a non-exporter firm, $EV(\infty)$, a new exporter, $EV(0)$, and a continuation exporter, $EV(1)$. The expected value of a non-exporter firm is

$$EV_i^s(\infty) = \int_{a_{p,i}^s}^{a_{0,i}^s} \left(\Pi_{0,i}^s a (P_i^s)^{\theta_s - 1} D_i^s \omega_{i,i}^s - W_i f_{p,i}^s + n_i Q_i EV_i^s(\infty) \right) \phi(a) da +$$

$$\int_{a_{0,i}^s}^{\infty} \left(\Pi_{0,i}^{s,i} a (P_i^s)^{\theta_s - 1} D_i^s \omega_{i,i}^s + \sum_{j \neq i} \frac{(P_j^s)^{\theta_s - 1} D_j^s \omega_{j,i}^s}{(\xi_{0,i,j}^s)^{\theta_s - 1} (\tau_{j,i}^s)^{\theta_s}} - W_i f_{p,i}^s - W_i f_{0,i}^s + n_i Q_i EV_i^s(0) \right) \phi(a) da.$$

Assuming that the productivity process follows a Pareto distribution with parameter $\eta > 1$, $\phi(a) = \eta a^{-\eta - 1}$, we have that

$$EV_i^s(\infty) = \Pi_{0,i}^s \left[(P_i^s)^{\theta_s - 1} D_i^s \omega_{i,i}^s \Psi_{p,i}^s + \sum_{j \neq i} (\xi_{0,i,j}^s)^{1-\theta_s} (\tau_{j,i}^s)^{-\theta_s} (P_j^s)^{\theta_s - 1} D_j^s \omega_{j,i}^s \Psi_{0,i}^s \right] \tag{8}$$

$$- W_i f_{p,i}^s n_{p,i}^s - W_i f_{0,i}^s n_{0,i}^s + n_i Q_i \left[(1 - n_{0,i}^s) EV_i^s(\infty) + n_{0,i}^s EV_i^s(0) \right];$$

where $\Psi_{p,i}^s = \frac{\eta}{\eta - 1} (a_{p,i}^s)^{1-\eta}$, $n_{p,i}^s = (a_{p,i}^s)^{-\eta}$, $\Psi_{0,i}^s = \frac{\eta}{\eta - 1} (a_{0,i}^s)^{1-\eta}$, and $n_{0,i}^s = (a_{0,i}^s)^{-\eta}$. Similarly, the expected values of a new exporter and a continuation exporter are respectively given by

$$EV_i^s(0) = \Pi_{0,i}^s \left[(P_i^s)^{\theta_s - 1} D_i^s \omega_{i,i}^s \Psi_{p,i}^s + \sum_{j \neq i} (\xi_{0,i,j}^s)^{1-\theta_s} (\tau_{j,i}^s)^{-\theta_s} (P_j^s)^{\theta_s - 1} D_j^s \omega_{j,i}^s \Psi_{0,i}^s \right] \tag{9}$$

$$-W_i f_{p,i}^s n_{p,i}^s - W_i f_{0,i}^s n_{0,i}^s + n_i Q_i \big[(1-n_{1,i}^s) EV_i^s(\infty) + n_{1,i}^s EV_i^s(1)\big],$$

and

$$EV_i^s(1) = \Pi_{0,i}^s \left[(P_i^s)^{\theta_s - 1} D_i^s \omega_i^s \Psi_{p,i}^s + \sum_{j \neq i} (\xi_{1,i,j}^s)^{1-\theta_s} (\tau_{j,i}^s)^{-\theta_s} (P_j^s)^{\theta_s - 1} D_j^s (1-\omega_i^s) \Psi_{1,i}^s \right] \quad (10)$$

$$-W_i f_{p,i}^s n_{p,i}^s - W_i f_{1,i}^s n_{1,i}^s + n_i Q_i \big[(1-n_{1,i}^s) EV_i^s(\infty) + n_{1,i}^s EV_i^s(1)\big].$$

Free entry and masses of firms Upon entry, new firms cannot immediately produce, instead they have to wait one period to start producing. After paying the fixed entry fee they get randomly and uniformly assigned into a sector. Hence, in equilibrium the entry cost should be equal to the expected average discounted value of entering:

$$W_i f_{e,i} = Q_i \sum_s \frac{EV_i^s(\infty)}{S}. \quad (11)$$

This firm allocation rule implies that the mass of firms that enters in each sector is the same, $N_{E,i,t}^s = \frac{N_{E,i,t}}{S}$. Every period a fraction of firms dies exogenously, and a new fraction enters the economy according to $N_{E,i,t}^s = (1-n_i) N_{i,t-1}^s$. Every period, the evolution of the number of firms is given by the survivors and the entrants, $N_{i,t}^s = n_i N_{i,t-1}^s + N_{E,i,t-1}^s$. Finally we can divide firms into non-exporters $N_{0,i,t}^s = N_{i,t}^s - N_{x,i,t}^s$, and exporters $N_{x,i,t}^s = N_{x1,i,t}^s + N_{x0,i,t}^s$, where $N_{x1,i,t}^s = n_i n_{1,i,t}^s N_{x,i,t-1}^s$ are continuation exporters, and $N_{x0,i,t}^s = n_{0,i,t}^s (N_{E,i,t-1}^s + n_i N_{0,i,t-1}^s)$ are new exporters.

2.2.5 Production of fossil energy

Fossil energy, which is used in the production of the sector-specific inputs, is produced with a Cobb-Douglas technology that combines labor L, energy-specific capital K^Z, and a flow of fossil resources Z^{ed}, which is an endowment. Fossil energy is produced competitively and the representative firm maximizes profits

$$max_{L_i^z, Z_i^{ed}} P^z Z_i - W_i L_i^z - R_i^z K_i^z - P_i^{z,e} Z_i^{ed},$$

subject to its technological constraint

$$Z_i = (L_i^z)^{1-\alpha_{z,i}-\mu_{z,i}} (K_i^z)^{\mu_{z,i}} (Z_i^{ed})^{\alpha_{z,i}}. \quad (12)$$

From the FOCs we find the optimal demands for labor, capital and fossil resources by the energy sector, given by $\frac{W_i}{P^z} = (1 - \alpha_{z,i} - \mu_{z,i})\frac{Z_i}{L_i^z}$, $\frac{R_i^z}{P^z} = \mu_{z,i}\frac{Z_i}{K_i^z}$, and $\frac{P_i^{z,e}}{P^z} = \alpha_{z,i}\frac{Z_i}{Z_i^{ed}}$ respectively. Energy is considered to be homogeneous across countries, and there's a global market for Z with a unique price for it, P^z.

2.3 Aggregates and equilibrium conditions

To close the model we obtain: sector prices, P_i^s; total labor demand, that includes labor used in production, $L_{i,p}^s$, and for fixed costs, $L_{f,i}^s$; aggregate capital per sector, K_i^s; tariff revenue, T_i^s; sector exports and imports, EX_i^s and IM_i^s; and profits, Π_i^s. And, we derive the equilibrium conditions for the labor, capital and foreign trade markets. As additional equilibrium condition we impose balanced trade (exports = imports) for each country.

Using the optimality conditions of the heterogeneous producers of sector-specific inputs and the productivity thresholds for producing and exporting, we can obtain the sectoral prices from equation 3:

$$P_i^s = \left[\omega_{i,i}^s N_i^s \left(\frac{\theta_s}{\theta_s - 1} MC_i^s\right)^{1-\theta_s} \Psi_{p,i}^s + \right.$$
$$\left. \sum_{j \neq i} \omega_{i,j}^s \left(\tau_{i,j}^s \frac{\theta_s}{\theta_s - 1}\right)^{1-\theta_s} MC_j^s \left(\frac{N_{x1,j}^s}{n_{1,j}^s} \frac{\Psi_{1,j}^s}{(\xi_{1,j,i}^s)^{\theta_s - 1}} + \frac{N_{x0,j,i}^s}{n_{0,j}^s} \frac{\Psi_{0,j}^s}{(\xi_{0,j,i}^s)^{1-\theta_s}}\right)\right]^{\frac{1}{1-\theta_s}}$$

We also need to write down the market clearing conditions for labor, capital and international trade. With this in mind, we first find the total labor used for production and fixed costs, that describe labor demand in the model:

$$L_{i,p}^s = (\theta_s - 1)\Pi_{0,i}^s \frac{1 - \alpha_s}{W_i} \left[N_i^s \Psi_{p,i}^s (P_i^s)^{1-\theta_s} D_i^s \omega_{i,i}^s + \right.$$
$$\left. \sum_{j \neq i} \frac{(P_j^s)^{\theta_s - 1}}{(\tau_{i,j}^s)^{\theta_s}} D_j^s \omega_{i,j}^s \left((\xi_{1,i}^s)^{1-\theta_s} \frac{N_{x1,i}^s}{n_{1,i}^s} \Psi_{1,i}^s + (\xi_{0,i}^s)^{1-\theta_s} \frac{N_{x0,i}^s}{n_{0,i}^s} \Psi_{0,i}^s\right)\right],$$

and

$$L_{f,i}^s = N_i^s n_{p,i}^s f_{p,i}^s + f_{0,i}^s N_{x0,i}^s + f_{1,i}^s N_{x1,i}^s + N_{E,i}^s f_{e,i}^s,$$

Then, we clear the labor market by equating supply and demand:

$$L_i = \sum_s (L_{i,p}^s + L_{f,i}^s) + L_i^z.$$

Second, using optimal labor demand and the properties from the Cobb-Douglas production function, we find the equilibrium for total capital:

$$K_i^s = \frac{\alpha_s}{\kappa_s}\frac{W_i}{R_i^s}L_{i,p}^s.$$

Third, regarding foreign trade equilibrium, we find sector export and imports, and we impose balanced trade:

$$EX_i^s = \sum_{j\neq i}\left[\frac{\theta_s \Pi_{0,i} D_j^s \omega_{j,i}^s}{(P_j^s)^{1-\theta_s}(\tau_{j,i}^s)^{\theta_s}}\left((\xi_{1,i,j}^s)^{1-\theta_s}\frac{N_{x1,i}^s}{n_{1,i}^s}\Psi_{1,i}^s + (\xi_{0,i,j}^s)^{1-\theta_s}\frac{N_{x0,i}^s}{n_{0,i}^s}\Psi_{0,i}^s\right)\right],$$

and the trade balance equilibrium is $\sum_s EX_i^s - \sum_s IM_i^s = P^z * (Z_i - \sum_s z_i^s)$.

Finally, two additional variables are important for the aggregate budget equilibrium, which are tariff revenue and sector profits:

$$T_i^s = \sum_{j\neq i}\left[\frac{(\tau_{i,j}^s - 1)\theta_s \Pi_{0,j} D_i^s \omega_{i,j}^s}{(P_i^s)^{1-\theta_s}(\tau_{i,j}^s)^{\theta_s}}\left((\xi_{1,j,i}^s)^{1-\theta_s}\frac{N_{x1,j}^s}{n_{1,j}^s}\Psi_{1,j}^s + (\xi_{0,j,i}^s)^{1-\theta_s}\frac{N_{x0,j}^s}{n_{0,j}^s}\Psi_{0,j}^s\right)\right],$$

$$\Pi_i^s = \Pi_{0,i}^s\left[\frac{N_i^s \Psi_{p,i}^s D_i^s \omega_{i,i}^s}{(P_i^s)^{1-\theta_s}} + \sum_{j\neq i}\left[\frac{(\tau_{j,i}^s)^{-\theta_s} D_j^s \omega_{j,i}^s}{(P_j^s)^{1-\theta_s}}\left(\frac{N_{x1,i}^s}{n_{1,i}^s}\frac{\Psi_{1,i}^s}{(\xi_{1,i,j}^s)^{\theta_s-1}} + \frac{N_{x0,i}^s}{n_{0,i}^s}\frac{\Psi_{0,i}^s}{(\xi_{0,i,j}^s)^{\theta_s-1}}\right)\right] - W_i L_{f,i}^s\right],$$

and

$$\Pi_{i,m} = \sum_s \Pi_{i,m}^s.$$

3 Data & Calibration

We calibrate the model for the Colombian economy using aggregate, sectoral, and firm-level data. Some of the parameters are taken directly from the literature, while others are targeted to match moments of the Colombian economy. Most of the data comes from the National Statistics Department (DANE) and includes information from national accounts, input-output matrices, and the annual manufacturing censuses for the 2010-2019 period.

First, we aggregate the sectoral information into two groups clean and dirty, where the latter corresponds to list of sectors in the EU CBAM proposal at a high risk of carbon leakage and with a high carbon intensity. In principle, these are the sectors that could eventually be targeted at a mature stage of the European CBAM. Then, we use the 2010 input-output matrix of the Colombian economy to calculate the sector-shares for the production of final goods (consumption and investment), and sector materials (intra- and inter-sectoral consumption). These values can be mapped directly from the data on expenditure shares after assuming unitary elasticities of substitution.

Then, we calibrate the iceberg and fixed costs to match the following sectoral moments: share of domestic gross output, trade openness, share of exporters, share of new exporters, size of new exporters, and exporter premium. For this, we use average data from the annual manufacturing survey. We also calibrate the relative size of the economies using the endowments of labor and the raw commodity.We find these values after minimizing a quadratic cost function between the data and model-implied moments. We assume that the 'climate conscious coalition' ROW_1 and the rest of the world ROW_2 are symmetric in size.[3]

Other parameters are taken from the literature, such as the discount factor, the capital, labor and material shares, the depreciation rate of capital, the elasticity of substitution between home and foreign goods, and the parameter corresponding to the Pareto distribution of the firm-specific productivity.

4 Scenario simulations

We study the effects of the BCA announcement and implementation by ROW_1, under different scenarios that change in two dimensions. First, whether the SOE implements stricter climate policy, in the form of a higher carbon tax (i.e., tax to the use of Z), upon the BCA announcement. Second, whether the BCA is based on a flat tariff to the dirty sector, or if after the implementation, tariffs to the dirty sector adjust proportionally with sector emissions.[4] The scenario without climate policy changes in the SOE and flat (unconditional) tariffs constitutes our benchmark scenario. Across scenarios the economy starts in its steady state without BCA and without carbon taxation in the SOE in year 0 (up to 2019). In year 1 (2020) ROW_1 credibly announces that a BCA covering dirty inputs imports is to be implemented in year

[3]This represents an optimistic scenario from the climate policy view point.

[4]The flat tariff scenario is meant to resemble a situation where tariffs are calculated based on some default emissions values at the sectoral level, whereas the conditional tariff adjustment reflects a situation where tariffs are continuously revised based on sectoral results.

11 (2030), and the SOE may or may not respond to this announcement by adjusting its own climate policy. In year 11 the BCA is implemented as announced, after that, the economy converges to the new steady state without further policy announcements/adjustments. The implementation of the BCA implies an increase in tariffs to dirty inputs imports coming into ROW_1 from 20% to 30%.[5]

4.1 Benchmark scenario: Flat BCA without climate policy response in SOE

From ROW_1's perspective, the announcement and implementation of the BCA makes imports of dirty inputs more costly, which reduces the demand for these inputs from abroad and hence shrinks the exports of the SOE and the ROW_2. Higher import costs also generate a sectoral reallocation in the ROW_1, since domestic input production partially substitute affected imports. As ROW_1 increases the production of dirty inputs, it allocates fewer factors of production to the clean sector and increases the demand for clean inputs from abroad. Higher demand for clean inputs partially offsets the negative impact on total exports in the SOE and ROW_2. These two economies experience a sector reallocation towards the clean sector, due to recomposition of foreign demand.

At the aggregate level (see Figure 1), the implementation of the BCA by ROW_1 is detrimental for the SOE, which sees a long-term reduction of aggregate consumption, exports, gross output and investment. All these variables already decrease after the BCA announcement, and before its implementation, the exception being investment which sees a temporary increase, due to the relative expansion of its clean sector. The negative effect on aggregate variables comes from a reduction in foreign demand from the ROW_1, which in turn affects domestic income.

At the sectoral level (see Figure 2), the implementation of the BCA deems capital in the dirty sector relatively less productive. As consequence, once the BCA is announced, the SOE witnesses a contraction of investment in dirty-specific capital (sector S_2) accompanied by an increase in clean investment (sector S_1). In turn, dirty exports and gross output contract, while clean exports and gross output increase. At the aggregate level the contraction of the dirty sector is partially offset by the expansion of the clean sector. The latter benefits from the factor reallocation in the domestic economy and the fact that ROW_1 increases its clean

[5] We abstract from including COVID-19 related shocks in the simulations

demand given that it needs to reallocate resources to the production of dirty inputs, to partially substitute imports with own production.

The transitional dynamics indicate that the sectoral recomposition experienced by the *SOE* is gradual. The stickiness in firm and trade dynamics (as seen in Figure 3) caused by the history-dependent fixed costs slows down the contraction of the dirty sector, whereas the expansion of the clean sector requires a costly capital build-up. This graduality in the adjustment has two visible consequences. First, while there is some reaction in anticipation to the BCA announcement, the lion's share of the effect is caused by the implementation itself. Second, during the transition aggregate consumption, gross output, and to a lesser extent exports, overshoot their long-term equilibrium.

Regarding firm's dynamics we observe some changes in the productivity thresholds to export in each sector. In particular, the dirty sector end ups with more productive firms exporting. As seen in 3, the drop in the mass of firms exporting (old and new) is larger than the drop in real exports, meaning that the average size of an exporter increases after the shock. The opposite is true for the clean sector where real exports increase relatively less than the mass of exporting firms, implying relatively smaller exporters on average.

4.2 Flat BCA with climate policy response in SOE

Next, we consider a scenario where upon the BCA announcement by ROW_1 the *SOE* immediately tightens its climate policy. This policy adjustment takes the form of an increase in taxes to the use of the fossil fuels Z (or equivalently an increase in carbon taxation). The proceeds from the fossil tax are rebated to households with a lump-sum subsidy.

We keep the magnitude and timing of the BCA as in the scenario without climate policy adjustment by the *SOE*. Figures 4 and 5 present the results of the scenario with *SOE* climate policy in response to the BCA announcement relative to the case where the *SOE* does not adjust its climate policy. At the aggregate level, the early implementation of stricter climate policy by the *SOE* is quantitatively indistinguishable from the case where no climate policy is implemented. This is explained by the fact that climate policy intensifies the asymmetric impact of the BCA on the dirty and clean sector by comparable proportions, and these additional sectoral effects cancel each other out in the aggregate. With climate policy in the *SOE* the clean sector has better footing both along the transition and in the long-run.

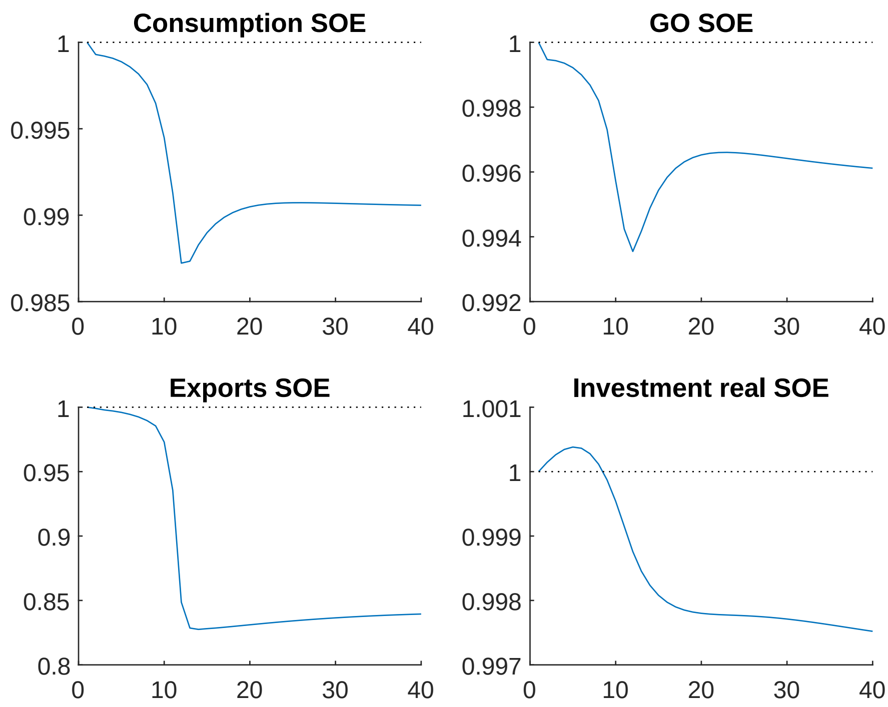

Figure 1: Flat BCA - Aggregate dynamics

Increase in tariffs to dirty sector exports to ROW_1 from 20% to 30%. Announced in year 1, implemented in year 11. All panels relative to initial equilibrium.

A notable effect of the climate policy response by the SOE is that it results in a substantial decrease in the intensity of fossil use, $Zint.$, by the two sectors (Bottom-center panel in Figure 5).

4.3 Conditional BCA without climate policy response in SOE

In this scenario we keep the timing of the announcement and implementation of the BCA as in the benchmark scenario. However, the implemented adjustment is now conditional on the actual use of Z by the dirty sector, relative to the initial steady state. Where if the use of Z remains unchanged relative to its baseline, the BCA prescribes a tariff adjustment is as in the flat BCA scenario. Relative to the initial equilibrium, in the absence of a policy response by the SOE, the conditional BCA (C) produces milder, albeit quantitatively similar,

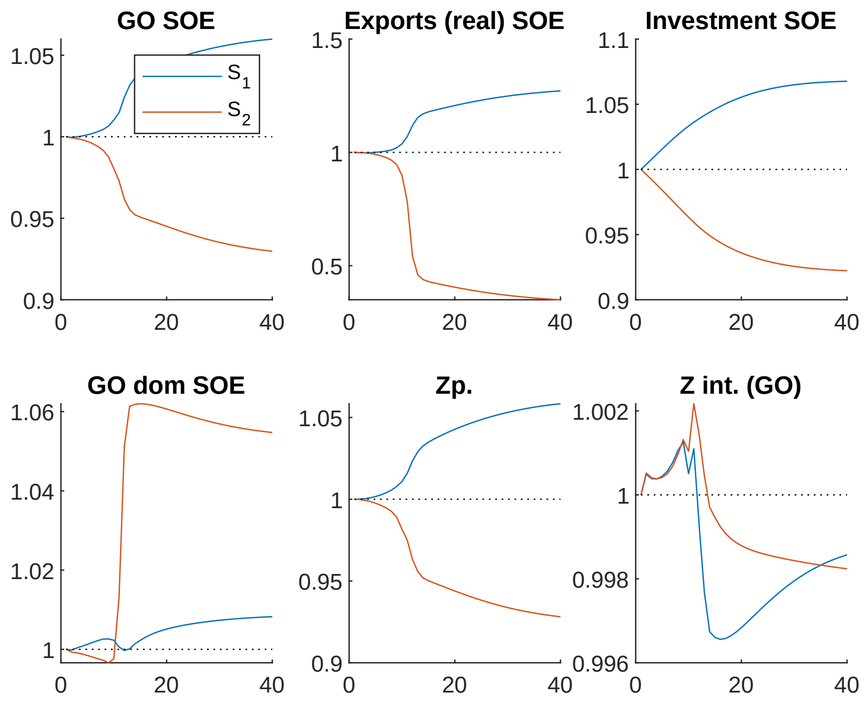

Figure 2: Flat BCA - Sectoral dynamics

Increase in tariffs to dirty sector exports to ROW_1 from 20% to 30%. Announced in year 1, implemented in year 11. All panels relative to initial equilibrium.

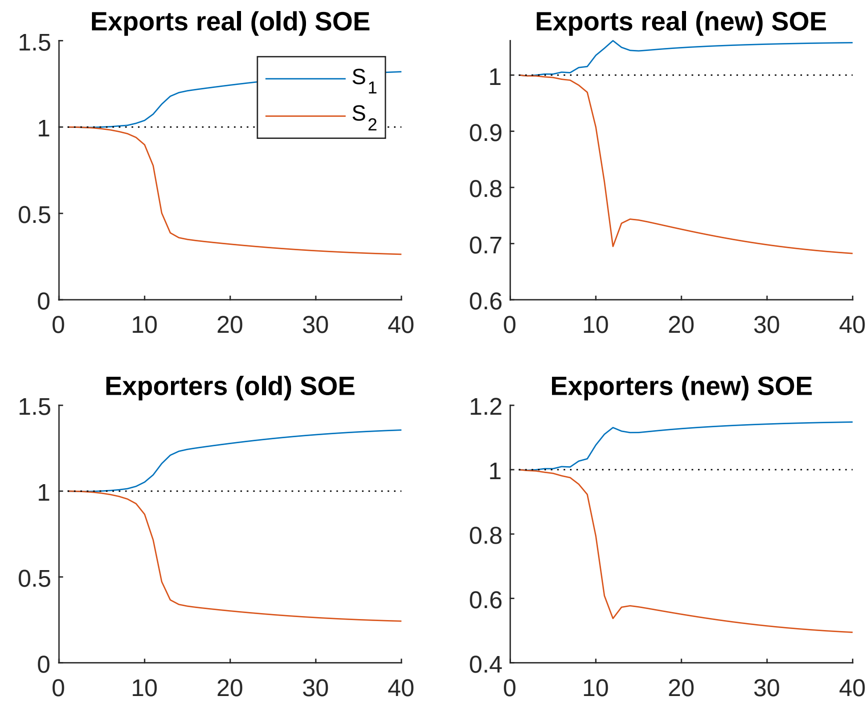

Figure 3: Flat BCA - Exporter dynamics

Increase in tariffs to dirty sector exports to ROW_1 from 20% to 30%. Announced in year 1, implemented in year 11. All panels relative to initial equilibrium.

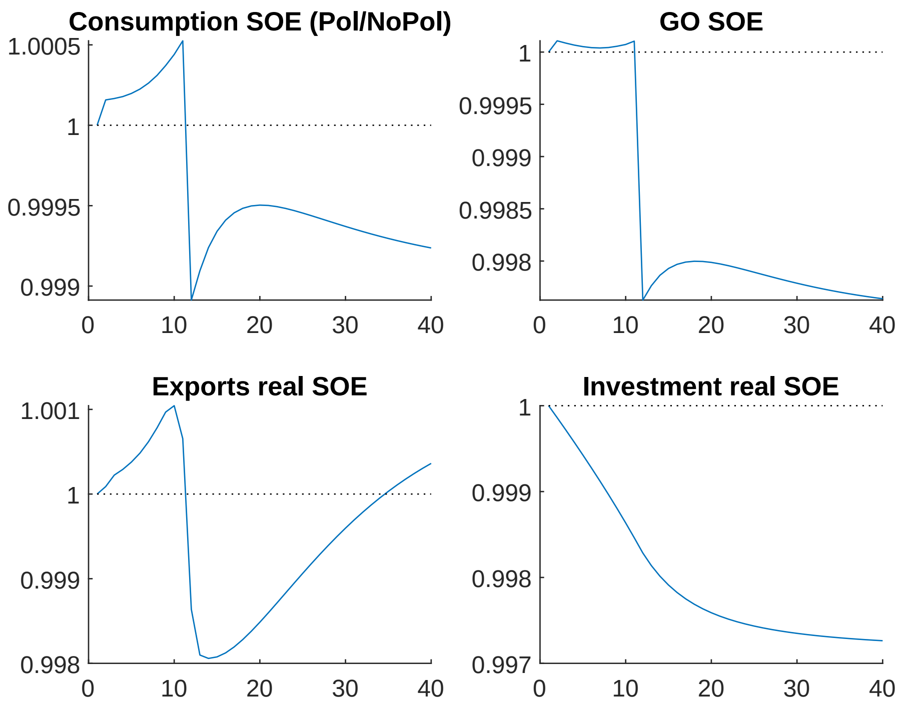

Figure 4: Flat BCA & SOE policy - Aggregate dynamics

Increase in tariffs to dirty sector exports to ROW_1 from 20% to 30%. Announced in year 1, implemented in year 11. Increase in taxes to Z in the SOE from 0 to 10% in year 1. All panels relative to flat BCA without SOE policy.

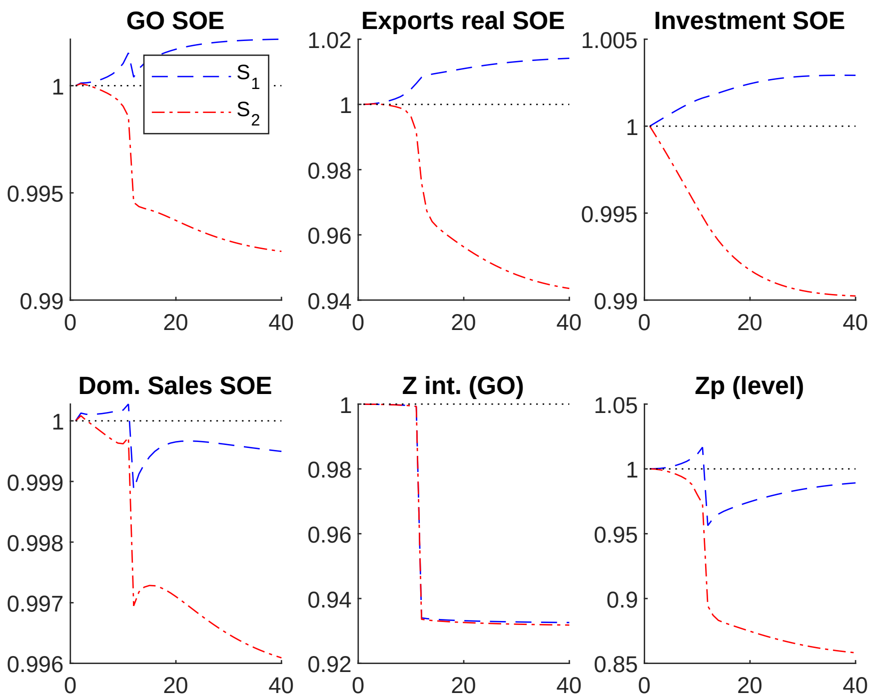

Figure 5: Flat BCA & SOE policy - Sectoral dynamics

Increase in tariffs to dirty sector exports to ROW_1 from 20% to 30%. Announced in year 1, implemented in year 11. Increase in taxes to Z in the SOE from 0 to 10% in year 1. All panels relative to flat BCA without SOE policy.

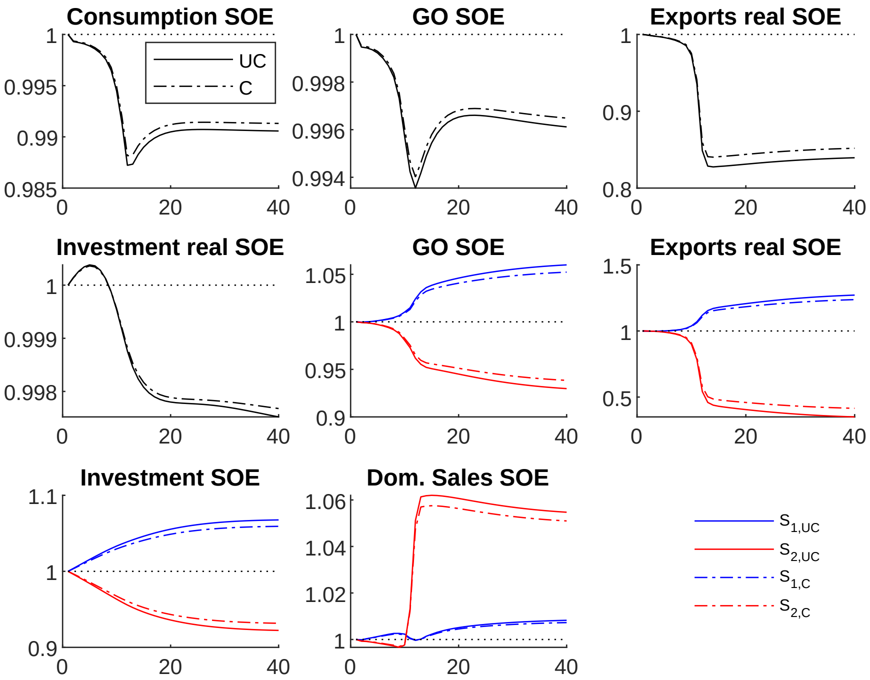

Figure 6: Flat BCA Vs. Conditional BCA - Aggregate and sectoral dynamics
Flat: Increase in tariffs to dirty sector exports to ROW_1 from 20% to 30%; Conditional: increase in tariffs to dirty sector exports to ROW_1 from 20% to 30%* $\frac{z_t^{dirty}}{z_0^{dirty}}$. Tariff increase announced in year 1, implemented in year 11. All panels relative to initial equilibrium.

aggregate and sectoral responses as those to the flat (i.e., unconditional, UC) BCA (see Figure 6). The differences between scenarios is only noticeable after the BCA implementation and is more pronounced as time passes by. This underscores the sluggishness of the market response, caused by the persistence induced by firm dynamics, to the BCA announcement. As expected, when comparing the responses under a flat BCA relative to a conditional one (Figure 7), the dirty sector fares worse in in the international markets if the tariff increase remains constant after implementation. Under a flat BCA exports of the dirty sector would be 15% lower than under a conditional BCA.

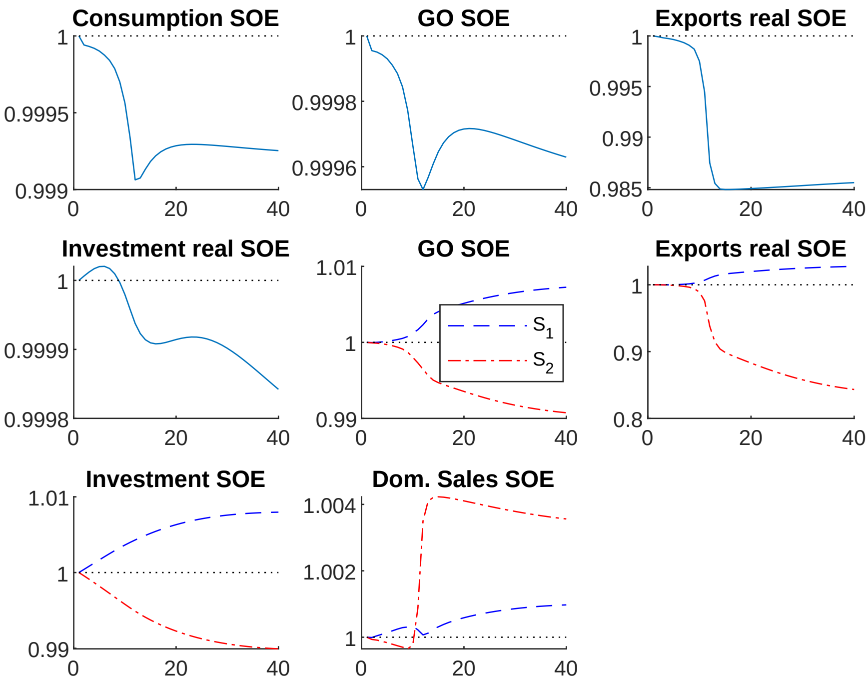

Figure 7: Flat BCA Vs. Conditional BCA - Aggregate and sectoral dynamics

Flat: Increase in tariffs to dirty sector exports to ROW_1 from 20% to 30%; Conditional: increase in tariffs to dirty sector exports to ROW_1 from 20% to 30%* $\frac{z_t^{dirty}}{z_0^{dirty}}$. Tariff increase announced in year 1, implemented in year 11. All panels flat BCA relative to conditional BCA.

4.4 Conditional BCA with climate policy response in SOE

In the absence of domestic climate policy whether the BCA is flat or conditional appears to have little aggregate effect. The same does not seem to hold when evaluating the impact of climate policy by the SOE in response to the BCA announcement. In the case of aggregate exports, the implementation of early climate policy partially mitigates the effect of the BCA, resulting in a lower reduction of aggregate exports relative to the initial equilibrium (see Figure 8). The impact of implementing climate policy in the SOE on aggregate consumption, gross output, and investment, relative to not doing so is more significant when the tariff hike is conditional on the use of Z (see Figures 8 and 9). The early implementation of climate policy when the BCA is conditional brings along transitional benefits in the form of higher aggregate consumption and gross output up prior to the implementation of the BCA. However, after the conditional BCA is implemented things turn around, and climate policy results in a permanent reduction in consumption and gross output relative to the case with no policy. The positive transitional effect is the result of the tax revenue recycling while the permanent effect has to do with overall higher production cost in the domestic economy. Under a conditional BCA, the implementation of climate policy by the SOE results in an intra-sectoral reduction in the use of Z (bottom-right panel Figure 10) which in turn, partially 'shields' dirty exports from the BCA implementation in ROW_1.

Interestingly, depending on the type of BCA implemented by ROW_1 the implementation of climate policy by the SOW has opposite sectoral effects (see Figure 10). In particular, rather than exacerbating the negative impact of the BCA on the dirty sector, the early implementation of climate policy partially alleviates this burden when the BCA is conditional, as seen by the higher gross output and real exports of the dirty input producers relative to the scenario where a conditional BCA is implemented but there is no SOE climate response. In contrast, the domestic clean sector is negatively impacted by the early implementation of climate policy by the SOE given a conditional BCA. This is explained by the fact that while climate policy increases the cost of using Z across the board (i.e., both sectors use fossil energy), and thus induces a reduction in the use of Z, only dirty input exporters are 'rewarded' for this reduction with a less stringent tariff hike upon the BCA implementation in ROW_1. This of course does not imply that the domestic dirty (clean) sector is better (worse) off under a conditional BCA and the implementation of domestic climate policy than without BCA and

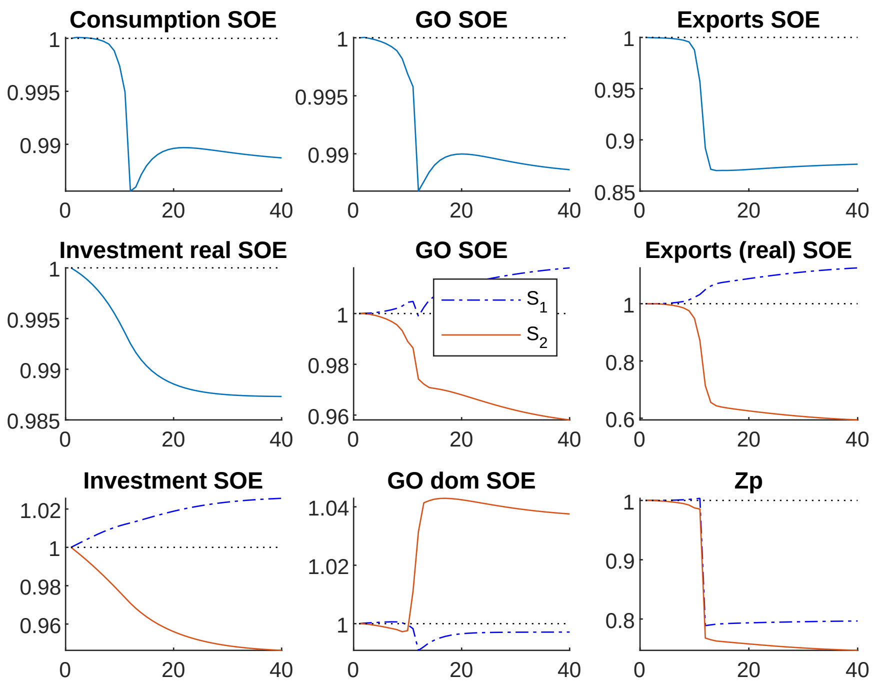

Figure 8: Conditional BCA & SOE policy.

Increase in tariffs to dirty sector exports to ROW_1 from 20% to 30%* $\frac{z_t^{dirty}}{z_0^{dirty}}$. Announced in year 1, implemented in year 11. Increase in taxes to Z in the SOE from 0 to 10% in year 1. All panels relative to initial equilibrium.

domestic climate policy. As seen in Figure 8, the domestic dirty sector losses from the BCA implementation, the introduction of domestic climate policy simply ameliorates these loses. In other words, given the announcement and implementation of a conditional BCA the domestic dirty sector is better off if the SOE implements early climate policy, while the opposite is true for the clean sector. From an environmental viewpoint, under a conditional BCA, the implementation of climate policy is rather effective at reducing the level and intensity fossil use in both SOE sectors (bottom-center and bottom right panels Figure 10).

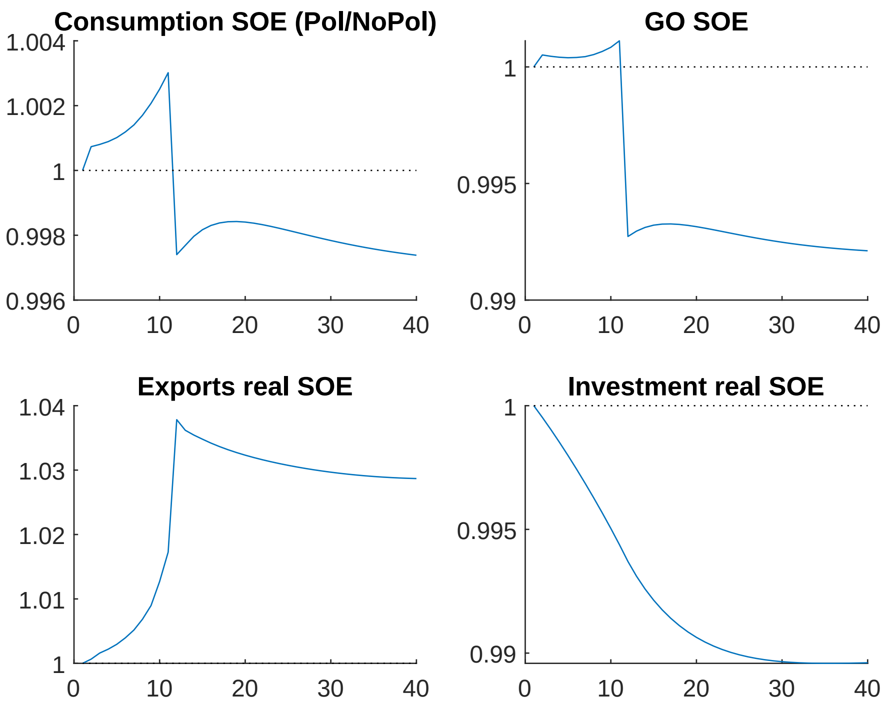

Figure 9: Conditional BCA & SOE policy - Aggregate dynamics

Increase in tariffs to dirty sector exports to ROW_1 from 20% to 30%* $\frac{z_t^{dirty}}{z_0^{dirty}}$. Announced in year 1, implemented in year 11. Increase in taxes to Z in the SOE from 0 to 10% in year 1. All panels relative to conditional BCA without SOE policy

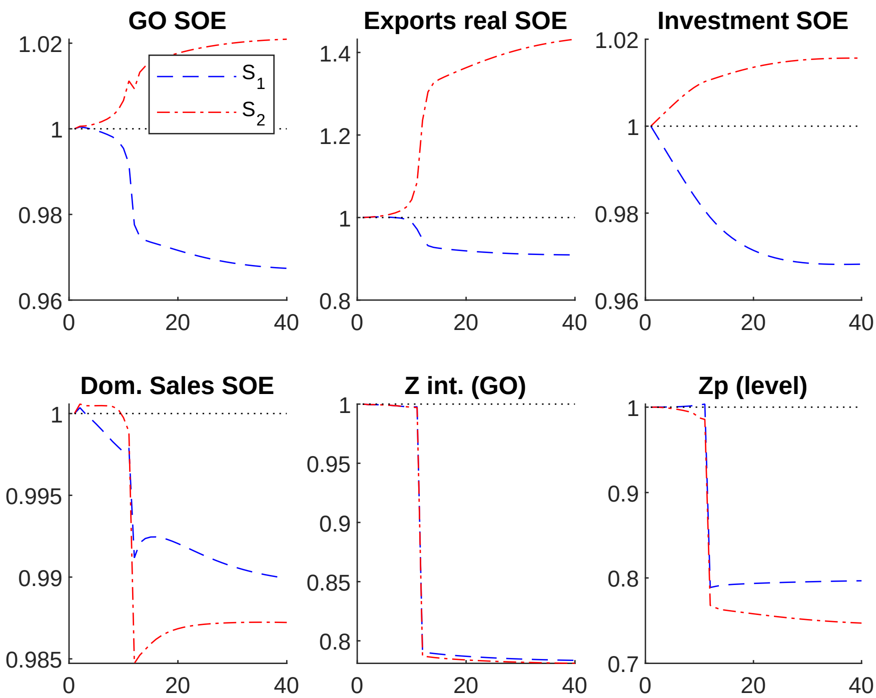

Figure 10: Conditional BCA & SOE policy - Sectoral dynamics

Increase in tariffs to dirty sector exports to ROW_1 from 20% to 30%* $\frac{z_t^{dirty}}{z_0^{dirty}}$. Announced in year 1, implemented in year 11. Increase in taxes to Z in the SOE from 0 to 10% in year 1. All panels relative to conditional BCA without SOE policy.

5 Discussion

To further compare the effects of the BCA under the different scenarios we compute the dynamic and static changes in welfare for the SOE. For the dynamic change, we calculate the present value of utility under a given scenario, and divide it over the utility in the initial steady state, as in equation (13). For the static change, we calculate the utility in the final steady state relative to the initial steady state, as in equation (14). Computing these two measures allows us to quantify the relevance of accounting for dynamics in our set up.

$$\Delta W_{dym} = \sum_{t=0}^{\infty} \beta^t log(C_t)/log(C_0) * 100 \tag{13}$$

$$\Delta W_{ss} = log(C_{new})/log(C_0) * 100 \tag{14}$$

Table 1 reports the welfare changes described above for the four scenarios studied in the preceding section: *1. Flat BCA; 2. Flat BCA with climate policy in SOE; 3. Conditional BCA; and 4. Conditional BCA with climate policy in SOE.* In all cases, the dynamic and static measures show that the SOE is worst off after the BCA implementation. We also find that the static measures overstate the welfare effects, since they do not take into account that the graduality of change created by firm and trade dynamics imply little losses in between the announcement and the implementation of the BCA. Additionally, these welfare comparisons reveal that, without any environmental considerations, overall welfare is always reduced by the implementation of policy in the SOE. Nonetheless, the case for a climate policy response by the SOE is even less favorable if one disregards the transitional effects of the policy and focuses on the static welfare effect.

To highlight the importance of static versus dynamic gains, we do an additional computation based on the benchmark scenario (Flat BCA without SOE policy). For this additional calculation we assume that, instead of the 10 years gap between BCA announcement and implementation, the BCA is simultaneously announced and implemented. This evidently does not alter the static comparison (-0.64), however, the dynamic change is magnified -0.80. This larger welfare drop is the consequence of the consumption overshooting that happens in the first period after the BCA announcement/implementation. In this case, consumers reduce their consumption by more in the first periods, which are the ones that matter the most for the dynamic change in welfare. This result demonstrates that a dynamic set up can capture the impact of the BCA not only in terms of its magnitude but also in terms of the announcement/implementation timing.

Finally, we observe that the SOE policy reduces welfare by more, because it increases production costs, affects domestic prices and shrinks consumption; and that the conditional BCA reduces welfare by less, since it implies a smaller increase in tariffs to the dirty sector.

Scenario	Static	Dynamic
Flat BCA	-0.64	-0.53
Flat BCA + SOE Policy	-0.74	-0.56
Conditional BCA	-0.59	-0.49
Conditional BCA + SOE Policy	-0.97	-0.57

Table 1: Welfare Analysis

6 Conclusions

In the current context where coordinated global climate policy appears difficult to achieve, BCAs have gained traction in the policymaking sphere as a complement to domestic carbon pricing. The case for BCAs is partly based on the potential of such schemes to reduce the competitiveness losses of the EITEs and mitigate the risk of carbon leakage. In addition to these direct benefits, BCAs can serve to spur climate action in other economies. The rationale behind this is that by implementing more stringent climate policy other economies can transition away from BCA-targeted sectors and reduce their exposure to tariff hike prescribed by the BCA. However, the required reallocation of factors between sectors that is needed to reduce the exposure to the BCA is costly itself and whether the BCA creates incentive for increasing climate efforts abroad depends on the perceived gain from reducing the exposure to a BCA relative to the cost of tightening climate policy.

We study the potential for BCAs to spur climate action in other economies. For this, we adopt the perspective of a small open economy facing the impending implementation of a BCA by a subset of its trading partners. In our setup, the BCA targets the imports of inputs produced with a relatively fossil-energy-intensive technology, used by firms in the 'climate conscious' economy. We assume that the BCA is announced prior to its implementation and explore the transitional effects on the SOE of the announcement and implementation of the BCA. Then we allow for climate policy tightening by the SOE, in the form of higher carbon taxation in response to the BCA announcement and evaluate if a future BCA implementation generates incentives for the SOE to tighten its own climate policy, beyond any environmental considerations.

Feeding our model with Colombian firm-level data we quantify the impact of the BCA on this SOE without and with a domestic climate policy response to the BCA announcement. Our results indicate that if the BCA design prescribes a flat tariff increase for dirty input imports, in the absence of a climate policy response the BCA has an overall negative aggregate effect on the SOE. The tightening of the climate policy by the SOE upon the BCA announcement has little aggregate effect relative to leaving policy unchanged. At the sectoral level the tightening of the domestic climate policy reinforces the impact of the BCA, generating relatively worse outcomes for the BCA-targeted sector.

We also consider an alternative BCA design where the tariff hike face by the targeted sector adjusts with its fossil energy use. Under this 'conditional' BCA design there may be scope for the implementation of early domestic policy in the SOE on the grounds of sectoral redistribution and compensation. By tightening its climate policy in response to a 'conditional' BCA, the SOE partially mitigates the losses of the sector targeted by the foreign BCA.

How the effect of domestic climate policy is affected by the BCA design has important political economy ramifications and may be crucial for determining the potential of BCAs as a climate policy coordination device. Depending on its design, a foreign BCA can potentially turn around the domestic balance of power between those in favor of the implementation of domestic climate policy and those against. This result warrants a deeper analysis of the redistributive and political economy considerations of domestic climate policy in the face of the unilateral implementation of a BCA by trading partners.

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A Complete model

Variables: $C_i, P_i^c, K_i^s, P_i^{K_s}, W_i, L_i, R_i^s, \Pi_i, T_i, X_i^{c,s}, D_i^c, P_i^s, I_i^s, X_i^{K_{s,s'}}, D_i^{K_s}, X_i^s,$
$D_i^s, MC_i^s, \Pi_{0,i}^s, a_{p,i}^s, a_{0,i}^s, a_{1,i}^s, n_{p,i}^s, n_{0,i}^s, n_{1,i}^s, \Psi_{p,i}^s, \Psi_{0,i}^s, \Psi_{1,i}^s, EV_i^s(0), EV_i^s(1),$
$N_i, N_i^s, N_{E,i}^s, N_{x,i}^s, N_{x1,i}^s, N_{x0,i}^s, N_{0,i}^s, L_{i,p}^s, L_{f,i}^s, EX_i^s, EX_i, \Pi_i^s$
Parameters: $\beta, \theta, \eta, \sigma_s, n_i, \delta^s, \omega_i^{c,s}, \omega_i^{K_s,s'}, \alpha_i^s, \theta_s, f_{e,i}, f_{p,i}^s, f_{0,i}^s, f_{1,i}^s, \xi_{0,i}^s, \xi_{1,i}^s, \tau_i^s,$

$$P_{i,t}^c C_{i,t} + \sum_s P_{i,t}^{K_s} I_{i,t}^s = W_{i,t} L_i + P_{i,t}^{z,e} Z_i^e + \sum_s \left(R_{i,t}^s K_{i,t}^s\right) + \Pi_{i,t} + T_{i,t}$$

$$K_{i,t+1}^s = I_{i,t}^s + \phi_k^s \left(\frac{I_{i,t}^s}{I_{i,t-1}^s} - 1\right)^2 - (1-\delta^s) K_{i,t}^s \tag{1}$$

$$\mu_{i,t}^s = \beta E_t U'(C_{i,t+1}) \frac{R_{i,t+1}^s}{P_{i,t+1}^c} + \mu_{i,t+1}^s (1-\delta^s) \tag{2}$$

$$U'(C_{i,t}) \frac{P^{K_s}}{P_{i,t}^c} = \mu_{i,t}^s \left(1 - \phi_k^s \left(\frac{I_{i,t}^s}{I_{i,t-1}^s} - 1\right) \frac{1}{I_{i,t-1}^s}\right) + \beta \mu_{i,t+1} \phi_k^s \left(\frac{I_{i,t+1}^s}{I_{i,t}^s} - 1\right) \frac{I_{i,t+1}^s}{(I_{i,t}^s)^2} \tag{3}$$

$$P_{i,t}^c = 1 \tag{4}$$

$$X_i^{c,s} = \omega_i^{c,s} \left(P_i^s\right)^{-\theta} \left(P_i^c\right)^{\theta-1} D_i^c \tag{5}$$

$$D_i^c = P_i^c C_i \tag{6}$$

$$P_i^c = \left(\sum_s \omega_i^{c,s} (P_i^s)^{1-\theta}\right)^{\frac{1}{1-\theta}} \tag{7}$$

$$M_{i,t}^s = \left(\sum_{s'} \left(\lambda_i^{M_{s,s'}}\right)^{\frac{1}{\sigma_{m,s}}} \left(X_{i,t}^{M_{s,s'}}\right)^{\frac{\sigma_{m,s}-1}{\sigma_{m,s}}}\right)^{\frac{\sigma_{m,s}}{\sigma_{m,s}-1}} \tag{8}$$

$$X_i^{M_{s,s'}} = \lambda_i^{M_{s,s'}} (P_i^{s'})^{-\sigma_{m,s}} (P_i^{M_s})^{\sigma_{m,s}-1} D_i^{M_s} \tag{9}$$

$$D_i^{M_s} = P_i^{M_s} M_i^{M_s} \tag{10}$$

$$P_i^{M_s} = \left(\sum_{s'} \lambda_{s'}^{i,M_s} (P_{s'}^i)^{1-\sigma_{m,s}} \right)^{\frac{1}{1-\sigma_{m,s}}} \tag{11}$$

$$X_i^{K_{s,s'}} = \omega_i^{K_{s,s'}} (P_i^{s'})^{-\sigma_s} (P_i^{K_s})^{\sigma_s - 1} D_i^{K_s} \tag{12}$$

$$D_i^{K_s} = P_i^{K_s} I_i^{K_s} \tag{13}$$

$$P_i^{K_s} = \left(\sum_{s'} \omega_{s'}^{i,K_s} (P_{s'}^i)^{1-\sigma_s} \right)^{\frac{1}{1-\sigma_s}} \tag{14}$$

$$X_i^s = X_i^{c,s} + \sum_{s'} X_i^{K_{s',s}} + \sum_{s'} X_i^{M_{s',s}} \tag{15}$$

$$D_i^s = P_i^s X_i^s \tag{16}$$

$$MC_i^s = \left((1 - \omega_i^{y,s}) \left(MC_i^{CD,s} \right)^{1-\gamma_i^s} + \omega_i^{y,s} \left(P^z \right)^{1-\gamma_i^s} \right)^{\frac{1}{1-\gamma_i^s}} \tag{17}$$

$$MC_i^{CD,s} = \left(\frac{R_i^s}{\alpha_i^s} \right)^{\alpha_i^s} \left(\frac{W_i}{1-\alpha_i^s} \right)^{\kappa_i^s} \left(\frac{P_i^{M_s}}{1-\alpha_i^s-\kappa_i^s} \right)^{1-\alpha_i^s-\kappa_i^s} \tag{18}$$

$$\Pi_{0,i}^s = \frac{1}{\theta_s} \left(\frac{\theta_s}{\theta_s - 1} MC_i^s \right)^{1-\theta_s} \tag{19}$$

$$a_{p,i}^s = \frac{W_i f_{p,i}^s}{\Pi_{0,i}^s (P_i^s)^{\theta_s - 1} D_i^s \omega_i^s} \tag{20}$$

$$W_i f_{0,i}^s = \frac{\Pi_{0,i}^s a_{0,i}^s (\xi_{0,i}^s)^{1-\theta_s} D_j^s (1-\omega_j^s)}{(\tau_j^s)^{\theta_s} (P_j^s)^{1-\theta_s}} + n_i Q_i \left(EV_i^s(1) - EV_i^s(\infty) \right) \tag{21}$$

$$W_i f_{1,i}^s = \frac{\Pi_{0,i}^s a_{1,i}^s (\xi_{1,i}^s)^{1-\theta_s} D_j^s (1-\omega_j^s)}{(\tau_j^s)^{\theta_s} (P_j^s)^{1-\theta_s}} + n_i Q_i \left(EV_i^s(1) - EV_i^s(\infty) \right) \tag{22}$$

$$EV_i^s(\infty, m) = \Pi_{0,i,m}^s (P_{i,m}^s)^{\theta_s - 1} D_{i,m}^s \omega_i^s \Psi_{p,i,m}^s - W_{i,m} f_{p,i}^s n_{p,i,m}^s + \tag{23}$$

$$(1 - n_{0,i,m}^s) n_i Q_{i,m} \left(\rho_m EV_i^s(\infty, m) + (1-\rho_m) EV_i^s(\infty, m') \right) +$$

$$\Pi^s_{0,i,m}(\xi^s_{0,i})^{1-\theta_s}(\tau^s_{j,m})^{-\theta_s}(P^s_{j,m})^{\theta_s-1}D^s_{j,m}(1-\omega^s_i)\Psi^s_{0,i} - W_{i,m}f^s_{0,i}n^s_{0,i,m}+$$
$$n^s_{0,i,m}n_iQ_{i,m}\left(\rho_m EV^s_i(0,m) + (1-\rho_m)EV^s_i(0,m')\right)$$

$$EV^s_i(0,m) = \Bigg[\Pi^s_{0,i,m}\big[(P^s_{i,m})^{\theta_s-1}D^s_{i,m}\omega^s_i\Psi^s_{p,i,m} + (\xi^s_{0,i})^{1-\theta_s}(\tau^s_{j,m})^{-\theta_s}(P^s_{j,m})^{\theta_s-1}D^s_{j,m}(1-\omega^s_i)\Psi^s_{0,i}\big]$$
$$-W_{i,m}f^s_{p,i}n^s_{p,i,m} - W_{i,m}f^s_{0,i}n^s_{0,i,m} + n_iQ_{i,m}\big[(1-n^s_{1,i,m})\left(\rho_m EV^s_i(\infty,m) + (1-\rho_m)EV^s_i(\infty,m')\right) +$$
$$n^s_{1,i,m}\left(\rho_m EV^s_i(1,m) + (1-\rho_m)EV^s_i(1,m')\right)\big]\Bigg] \tag{24}$$

$$EV^s_i(1,m) = \Bigg[\Pi^s_{0,i,m}\big[(P^s_{i,m})^{\theta_s-1}D^s_{i,m}\omega^s_i\Psi^s_{p,i,m} + (\xi^s_{1,i})^{1-\theta_s}(\tau^s_{j,m})^{-\theta_s}(P^s_{j,m})^{\theta_s-1}D^s_{j,m}(1-\omega^s_i)\Psi^s_{1,i}\big]$$
$$-W_{i,m}f^s_{p,i}n^s_{p,i,m} - W_{i,m}f^s_{1,i}n^s_{1,i,m} + n_iQ_{i,m}\big[(1-n^s_{1,i,m})\left(\rho_m EV^s_i(\infty,m) + (1-\rho_m)EV^s_i(\infty,m')\right) +$$
$$n^s_{1,i,m}\left(\rho_m EV^s_i(1,m) + (1-\rho_m)EV^s_i(1,m')\right)\big]\Bigg] \tag{25}$$

$$\Psi^s_{p,i,m} = \frac{\eta}{\eta-1}(a^s_{p,i,m})^{1-\eta} \tag{26}$$

$$\Psi^s_{0,i,m} = \frac{\eta}{\eta-1}(a^s_{0,i,m})^{1-\eta} \tag{27}$$

$$\Psi^s_{1,i,m} = \frac{\eta}{\eta-1}(a^s_{1,i,m})^{1-\eta} \tag{28}$$

$$n^s_{p,i,m} = (a^s_{p,i,m})^{-\eta} \tag{29}$$

$$n^s_{0,i,m} = (a^s_{0,i,m})^{-\eta} \tag{30}$$

$$n^s_{1,i,m} = (a^s_{1,i,m})^{-\eta} \tag{31}$$

$$W_{i,m}f_{e,i} = Q_{i,m}\sum_s \frac{EV^s_i(\infty,m)}{S} \tag{32}$$

$$N^s_{i,m,t} = \frac{N_{i,m,t}}{S} \tag{33}$$

$$N^s_{E,i,m,t} = (1-n_i)N^s_{i,m,t-1}$$

$$N^s_{i,m,t} = n_i N^s_{i,m,t-1} + N^s_{E,i,m,t-1} \tag{34}$$

$$N^s_{x,i,m,t} = N^s_{x1,i,m,t} + N^s_{x0,i,m,t} \tag{35}$$

$$N^s_{x1,i,m,t} = n_i n^s_{1,i,m,t} N^s_{x,i,m,t-1} \tag{36}$$

$$N^s_{x0,i,m,t} = n^s_{0,i,m,t}(N^s_{E,i,m,t-1} + n_i N^s_{0,i,m,t-1}) \tag{37}$$

$$N^s_{i,m,t} = N^s_{x,i,m,t} + N^s_{0,i,m,t} \tag{38}$$

$$P^s_{i,m,t} = \left[\omega^s_i N^s_{i,m,t}\left(\frac{\theta_s}{\theta_s-1}MC^s_{i,m,t}\right)^{1-\theta_s}\Psi^s_{p,i,m,t} + (1-\omega^s_i)\left(\tau^s_{i,m,t}\frac{\theta_s}{\theta_s-1}MC^s_{j,m,t}\right)^{1-\theta_s}\right. \tag{39}$$
$$\left.\left((\xi^s_{1,j})^{1-\theta_s}\frac{N^s_{x1,j,m,t}}{n^s_{1,j,m,t}}\Psi^s_{1,j,m,t} + (\xi^s_{0,j})^{1-\theta_s}\frac{N^s_{x0,j,m,t}}{n^s_{0,j,m,t}}\Psi^s_{0,j,m,t}\right)\right]^{\frac{1}{1-\theta_s}}$$

$$L^s_{i,p,m} = (\theta_s-1)\Pi^s_{0,i,m}\frac{1-\alpha_s}{W_i}\left[N^s_{i,m}\Psi^s_{p,i,m}(P^s_{i,m})^{\theta_s-1}D^s_{i,m}\omega^s_i + \right. \tag{40}$$
$$\left.(\tau^s_{j,m})^{-\theta_s}(P^s_{j,m})^{\theta_s-1}D^s_{j,m}(1-\omega^s_i)\left((\xi^s_{1,i})^{1-\theta_s}\frac{N^s_{x1,i,m,t}}{n^s_{1,i,m,t}}\Psi^s_{1,i,m,t} + (\xi^s_{0,i})^{1-\theta_s}\frac{N^s_{x0,i,m,t}}{n^s_{0,i,m,t}}\Psi^s_{0,i,m,t}\right)\right]$$

$$L^s_{f,i,m} = N^s_{i,m}n^s_{p,i,m}f^s_{p,i} + f^s_{0,i}N^s_{x0,i,m} + f^s_{1,i}N^s_{x1,i,m} + N^s_{E,i,m}f^s_{e,i} \tag{41}$$

$$L_{i,m} = \sum_s (L^s_{i,p,m} + L^s_{f,i,m}) \tag{42}$$

$$K^s_{i,m} = \frac{\alpha_s}{1-\alpha_s}\frac{W_{i,m}}{R^s_{i,m}}L^s_{i,p,m} \tag{43}$$

$$T^s_{i,m} = (\tau^s_{i,m} - 1)\theta_s \Pi_{0,j,m}(P^s_{i,m})^{\theta_s - 1} D^s_{i,m}(1-\omega^s_j)(\tau^s_{i,m})^{-\theta_s}\Bigg((\xi^s_{1,j})^{1-\theta_s}\frac{N^s_{x1,j,m,t}}{n^s_{1,j,m,t}}\Psi^s_{1,j,m,t} + \tag{44}$$

$$(\xi^s_{0,j})^{1-\theta_s}\frac{N^s_{x0,j,m,t}}{n^s_{0,j,m,t}}\Psi^s_{0,j,m,t}\Bigg)$$

$$EX^s_{i,m} = \theta_s \Pi_{0,i,m}(P^s_{j,m})^{\theta_s - 1} D^s_{j,m}(1-\omega^s_i)(\tau^s_{j,m})^{-\theta_s}\Bigg((\xi^s_{1,i})^{1-\theta_s}\frac{N^s_{x1,i,m,t}}{n^s_{1,i,m,t}}\Psi^s_{1,i,m,t} + \tag{45}$$

$$(\xi^s_{0,i})^{1-\theta_s}\frac{N^s_{x0,i,m,t}}{n^s_{0,i,m,t}}\Psi^s_{0,i,m,t}\Bigg)$$

$$EX_{i,m} = \sum_s EX^s_{i,m} \tag{46}$$

$$EX_{i,m} = EX_{j,m} \tag{47}$$

$$\Pi^s_{i,m} = \Pi^s_{0,i,m}\Bigg[N^s_{i,m}\Psi^s_{p,i,m}(P^s_{i,m})^{\theta_s - 1} D^s_{i,m}\omega^s_i + (\tau^s_{j,m})^{-\theta_s}(P^s_{j,m})^{1-\theta_s} D^s_{j,m}(1-\omega^s_i) \tag{48}$$

$$\Bigg((\xi^s_{1,i})^{1-\theta_s}\frac{N^s_{x1,i,m,t}}{n^s_{1,i,m,t}}\Psi^s_{1,i,m,t} + (\xi^s_{0,i})^{1-\theta_s}\frac{N^s_{x0,i,m,t}}{n^s_{0,i,m,t}}\Psi^s_{0,i,m,t}\Bigg)\Bigg] - W_{i,m} f L^s_{f,i}$$

$$\Pi_{i,m} = \sum_s \Pi^s_{i,m} \tag{49}$$

A.1 Steady State

$$P^c_i C_i = W_i \sum_s L^s_i + \sum_s \left(R^s_i K^s_i - \delta^s P^{K_s}_i K^s_i\right) + \Pi_i + T_i$$

$$P^c_i = 1 \tag{1}$$

$$U'(C_i)\frac{P^{K_s}_i}{P^c_i} = \beta U'(C_i)\frac{P^{K_s}_i}{P^c_i}\left(\frac{R^s_i}{P^{K_s}_i} + (1-\delta^s)\right)$$

$$1 = \beta\left(\frac{R^s_i}{P^{K_s}_i} + (1-\delta^s)\right) \tag{2}$$

$$X_i^{c,s} = \omega_i^{c,s} \left(P_i^s\right)^{-\theta} \left(P_i^c\right)^{\theta-1} D_i^c \tag{3}$$

$$D_i^c = P_i^c C_i \tag{4}$$

$$P_i^c = \left(\sum_s \omega_i^{c,s} (P_i^s)^{1-\theta} \right)^{\frac{1}{1-\theta}} \tag{5}$$

$$I_i^s = \delta^s K_i^s \tag{6}$$

$$X_i^{K_s,s'} = \omega_i^{K_s,s'} (P_i^{s'})^{-\sigma_s} (P_i^{K_s})^{\sigma_s - 1} D_i^{K_s} \tag{7}$$

$$D_i^{K_s} = P_i^{K_s} I_i^{K_s} \tag{8}$$

$$P_i^{K_s} = \left(\sum_{s'} \omega_{s'}^{i,K_s} (P_{s'}^i)^{1-\sigma_s} \right)^{\frac{1}{1-\sigma_s}} \tag{9}$$

$$X_i^s = X_i^{c,s} + \sum_{s'} X_i^{K_{s'},s} \tag{10}$$

$$D_i^s = P_i^s X_i^s \tag{11}$$

$$MC_i^s = \left(\frac{R_i^s}{\alpha_i^s} \right)^{\alpha_i^s} \left(\frac{W_i}{1-\alpha_i^s} \right)^{1-\alpha_i^s} \tag{12}$$

$$\Pi_{0,i}^s = \frac{1}{\theta_s} \left(\frac{\theta_s}{\theta_s - 1} MC_i^s \right)^{1-\theta_s} \tag{13}$$

$$a_{p,i}^s = \frac{W_i f_{p,i}^s}{\Pi_{0,i}^s (P_i^s)^{\theta_s - 1} D_i^s \omega_i^s} \tag{14}$$

$$W_i f_{0,i}^s = \frac{\Pi_{0,i}^s a_{0,i}^s (\xi_{0,i}^s)^{1-\theta_s} D_j^s (1-\omega_j^s)}{(\tau_j^s)^{\theta_s} (P_j^s)^{1-\theta_s}} + n_i Q_i \left(EV_i^s(1) - EV_i^s(\infty) \right) \tag{15}$$

$$W_i f_{1,i}^s = \frac{\Pi_{0,i}^s a_{1,i}^s (\xi_{1,i}^s)^{1-\theta_s} D_j^s (1-\omega_j^s)}{(\tau_j^s)^{\theta_s} (P_j^s)^{1-\theta_s}} + n_i Q_i \left(EV_i^s(1) - EV_i^s(\infty) \right) \tag{16}$$

$$EV_i^s(\infty) = \Pi_{0,i}^s \left[(P_i^s)^{\theta_s - 1} D_i^s \omega_i^s \Psi_{p,i}^s \right] \tag{17}$$

$$-W_i f_{p,i}^s n_{p,i}^s + n_i Q_i \left[(1 - n_{0,i}^s) EV_i^s(\infty) + + n_{0,i}^s EV_i^s(0) \right]$$

$$EV_i^s(0) = \Pi_{0,i}^s \Big[(P_i^s)^{\theta_s - 1} D_i^s \omega_i^s \Psi_{p,i}^s + (\xi_{0,i}^s)^{1-\theta_s} (\tau_j^s)^{-\theta_s} (P_j^s)^{\theta_s - 1} D_j^s (1-\omega_i^s) \Psi_{0,i}^s \Big] \tag{18}$$

$$-W_i f_{p,i}^s n_{p,i}^s - W_i f_{0,i}^s n_{0,i}^s + n_i Q_i \Big[(1 - n_{1,i}^s) EV_i^s(\infty) + n_{1,i}^s EV_i^s(1) \Big]$$

$$EV_i^s(1) = \Pi_{0,i}^s \Big[(P_i^s)^{\theta_s - 1} D_i^s \omega_i^s \Psi_{p,i}^s + (\xi_{1,i}^s)^{1-\theta_s} (\tau_j^s)^{-\theta_s} (P_j^s)^{\theta_s - 1} D_j^s (1-\omega_i^s) \Psi_{1,i}^s \Big] \tag{19}$$

$$-W_i f_{p,i}^s n_{p,i}^s - W_i f_{1,i}^s n_{1,i}^s + n_i Q_i \Big[(1 - n_{1,i}^s) EV_i^s(\infty) + n_{1,i}^s EV_i^s(1) \Big]$$

$$\Psi_{p,i}^s = \frac{\eta}{\eta - 1} (a_{p,i}^s)^{1-\eta} \tag{20}$$

$$\Psi_{0,i}^s = \frac{\eta}{\eta - 1} (a_{0,i}^s)^{1-\eta} \tag{21}$$

$$\Psi_{1,i}^s = \frac{\eta}{\eta - 1} (a_{1,i}^s)^{1-\eta} \tag{22}$$

$$n_{p,i}^s = (a_{p,i}^s)^{-\eta} \tag{23}$$

$$n_{0,i}^s = (a_{0,i}^s)^{-\eta} \tag{24}$$

$$n_{1,i}^s = (a_{1,i}^s)^{-\eta} \tag{25}$$

$$W_i f_{e,i} = Q_i \sum_s \frac{EV_i^s(0)}{S} \tag{26}$$

$$N_i^s = \frac{N_i}{S} \tag{27}$$

$$N_{E,i}^s = (1 - n_i) N_i^s \tag{28}$$

$$N_{x,i}^s = N_{x1,i}^s + N_{x0,i}^s \tag{29}$$

$$N_{x1,i}^s = n_i n_{1,i}^s N_{x,i}^s \tag{30}$$

$$N_{x0,i}^s = n_{0,i}^s (N_{E,i}^s + n_i N_{0,i}^s) \tag{31}$$

$$N_i^s = N_{x,i}^s + N_{0,i}^s \tag{32}$$

$$P_i^s = \left[\omega_i^s N_i^s \left(\frac{\theta_s}{\theta_s - 1} MC_i^s \right)^{1-\theta_s} \Psi_{p,i}^s + (1 - \omega_i^s) \left(\tau_i^s \frac{\theta_s}{\theta_s - 1} MC_j^s \right)^{1-\theta_s} \right. \\ \left. \left((\xi_{1,j}^s)^{1-\theta_s} \frac{N_{x1,j}^s}{n_{1,j}^s} \Psi_{1,j}^s + (\xi_{0,j}^s)^{1-\theta_s} \frac{N_{x0,j}^s}{n_{0,j}^s} \Psi_{0,j}^s \right) \right]^{\frac{1}{1-\theta_s}} \tag{33}$$

$$L_{i,p}^s = (\theta_s - 1) \Pi_{0,i}^s \frac{1 - \alpha_s}{W_i} \left[N_i^s \Psi_{p,i}^s (P_i^s)^{\theta_s - 1} D_i^s \omega_i^s + \right. \\ \left. (\tau_j^s)^{-\theta_s} (P_j^s)^{\theta_s - 1} D_j^s (1 - \omega_i^s) \left((\xi_{1,i}^s)^{1-\theta_s} \frac{N_{x1,i}^s}{n_{1,i}^s} \Psi_{1,i}^s + (\xi_{0,i}^s)^{1-\theta_s} \frac{N_{x0,i}^s}{n_{0,i}^s} \Psi_{0,i}^s \right) \right] \tag{34}$$

$$L_{f,i}^s = N_i^s n_{p,i}^s f_{p,i}^s + f_{0,i}^s N_{x0,i}^s + f_{1,i}^s N_{x1,i}^s + N_{E,i}^s f_{e,i}^s \tag{35}$$

$$L_i = \sum_s (L_{i,p}^s + L_{f,i}^s) \tag{36}$$

$$K_i^s = \frac{\alpha_s}{1 - \alpha_s} \frac{W_i}{R_i^s} L_{i,p}^s \tag{37}$$

$$T_i^s = (\tau_i^s - 1) \theta_s \Pi_{0,j} (P_i^s)^{\theta_s - 1} D_i^s (1 - \omega_i^s) (\tau_i^s)^{-\theta_s} \left((\xi_{1,j}^s)^{1-\theta_s} \frac{N_{x1,j}^s}{n_{1,j}^s} \Psi_{1,j}^s + (\xi_{0,j}^s)^{1-\theta_s} \frac{N_{x0,j}^s}{n_{0,j}^s} \Psi_{0,j}^s \right) \tag{38}$$

$$EX_i^s = \theta_s \Pi_{0,i} (P_j^s)^{\theta_s - 1} D_j^s (1 - \omega_j^s)(\tau_j^s)^{-\theta_s} \left((\xi_{1,i}^s)^{1-\theta_s} \frac{N_{x1,i}^s}{n_{1,i}^s} \Psi_{1,i}^s + (\xi_{0,i}^s)^{1-\theta_s} \frac{N_{x0,i}^s}{n_{0,i}^s} \Psi_{0,i}^s \right) \tag{39}$$

$$EX_i = \sum_s EX_i^s \tag{40}$$

$$EX_i = EX_j \tag{41}$$

$$\Pi_i^s = \Pi_{0,i}^s \Bigg[N_i^s \Psi_{p,i}^s (P_i^s)^{\theta_s - 1} D_i^s \omega_i^s + (\tau_j^s)^{-\theta_s} (P_j^s)^{\theta_s - 1} D_j^s (1 - \omega_i^s) \left((\xi_{1,j}^s)^{1-\theta_s} \frac{N_{x1,j}^s}{n_{1,j}^s} \Psi_{1,j}^s + (\xi_{0,j}^s)^{1-\theta_s} \frac{N_{x0,j}^s}{n_{0,j}^s} \Psi_{0,j}^s \right) \Bigg] - W_i L_{f,i}^s \tag{42}$$

$$\Pi_i = \sum_s \Pi_i^s \tag{43}$$

B Calibration - Parameters

Parameter	Value	Definition	Source
L_i	$[10; 50; 50]$	Population	Calibration
β	0.96	Discount factor	Literature
η	2.0	Pareto distribution	Literature
θ	1.01	Elast. of subs. C	Cobb-Douglas
n	$[0.90; 0.90; 0.90]$	Survival probability	Calibration
δ_i^s	$\begin{bmatrix} 0.1 & 0.1 \\ 0.1 & 0.1 \\ 0.1 & 0.1 \end{bmatrix}$	K depreciation	Literature
$\omega_{c,i}^s$	$\begin{bmatrix} 0.5 & 0.5 \\ 0.5 & 0.5 \\ 0.5 & 0.5 \end{bmatrix}$	Sector shares in C	Calibration
σ_i^s	$\begin{bmatrix} 1.01 & 1.01 \\ 1.01 & 1.01 \\ 1.01 & 1.01 \end{bmatrix}$	Elast. of subs. I	Cobb-Douglas
$\omega_{k,i}^s$	$\begin{bmatrix} 0.5, 0.5 \\ 0.5, 0.5 \end{bmatrix} \begin{bmatrix} 0.5, 0.5 \\ 0.5, 0.5 \end{bmatrix} \begin{bmatrix} 0.5, 0.5 \\ 0.5, 0.5 \end{bmatrix}$	Sector shares I	Calibration
α_i^s	$\begin{bmatrix} 0.3 & 0.3 \\ 0.3 & 0.3 \\ 0.3 & 0.3 \end{bmatrix}$	Capital Share	Literature/Calib
θ_i^s	$\begin{bmatrix} 3.5 & 3.5 \\ 3.5 & 3.5 \\ 3.5 & 3.5 \end{bmatrix}$	$Elast.of$ $subs.H\&F$	Literature

Table 2: Parameters. The sub-index i stands for country i and super-index s for sector s. Columns are related to sectors and rows to countries.

Parameter	Value	Definition	Source
ω_i^s	$\begin{bmatrix} 0.6, 0.2, 0.2 \\ 0.6, 0.2, 0.2 \end{bmatrix} \begin{bmatrix} 0.015, 0.8325, 0.15 \\ 0.015, 0.8325, 0.15 \end{bmatrix} \begin{bmatrix} 0.015, 0.15, 0.8325 \\ 0.015, 0.15, 0.8325 \end{bmatrix}$	Home bias	Calibration
$f_{e,i}$	[4.0; 4.0; 4.0]	Entry cost	Normalization
$f_{p,i}^s$	$\begin{bmatrix} 5.5 & 5.5 \\ 15.125 & 15.125 \\ 15.125 & 15.125 \end{bmatrix}$	$Production$ $cost$	Calibration
$f_{0,i}^s$	$\begin{bmatrix} 0.595 & 0.595 \\ 0.28 & 0.28 \\ 0.28 & 0.28 \end{bmatrix}$	$Export$ $cost - new$	Calibration
$f_{1,i}^s$	$\begin{bmatrix} 1.14 & 1.11 \\ 0.855 & 0.855 \\ 0.855 & 0.855 \end{bmatrix}$	$Export$ $cost - old$	Calibration
$\xi_{0,i,j}^s$	$\begin{bmatrix} 1.0, 2.25, 2.25 \\ 1.0, 2.25, 2.25 \end{bmatrix} \begin{bmatrix} 1.6, 1.0, 1.6 \\ 1.6, 1.0, 1.6 \end{bmatrix} \begin{bmatrix} 1.6, 1.6, 1.0 \\ 1.6, 1.6, 1.0 \end{bmatrix}$	Iceberg new	Calibration
$\xi_{1,i,j}^s$	$\begin{bmatrix} 1.0, 1.025, 1.025 \\ 1.0, 1.025, 1.025 \end{bmatrix} \begin{bmatrix} 1.025, 1.0, 1.025 \\ 1.025, 1.0, 1.025 \end{bmatrix} \begin{bmatrix} 1.025, 1.025, 1.0 \\ 1.025, 1.025, 1.0 \end{bmatrix}$	Iceberg old	Calibration
$\tau_{i,j}^s$	$\begin{bmatrix} 1.0, 1.20, 1.20 \\ 1.0, 1.20, 1.20 \end{bmatrix} \begin{bmatrix} 1.20, 1.0, 1.20 \\ 1.20, 1.0, 1.20 \end{bmatrix} \begin{bmatrix} 1.20, 1.20, 1.0 \\ 1.20, 1.20, 1.0 \end{bmatrix}$	Tariffs	Calibration

Table 3: Parameters (continuation). The sub-index i stands for country i and super-index s for sector s. Columns are related to