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Abstract

Alternative perspectives on the structure of international trade have important implications for the evaluation of climate policy. In this paper we assess climate policy in the context of three important alternative trade formulations. First is a Heckscher-Ohlin model based on trade in homogeneous products, which establishes the traditional neoclassical view on comparative advantage. Second is an Armington model based on regionally differentiated goods, which constitutes a popular specification for numerical simulations of trade policy. Third is a Melitz model based on monopolistic-competition and firm heterogeneity. This heterogeneous-firms framework is adopted in many contemporary theoretic and empirical investigations in international trade. As we show in this paper, the three alternative trade formulations have important implications for the assessment of climate policy with respect to competitive effects for energy-intensive production (and hence carbon leakage) as well as the transmission of policy burdens across countries.

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1 Introduction

Countries considering subglobal or unilateral regulation of transboundary pollutants are rightly concerned with the potential for these policies to be undermined through international spillover effects. In the context of climate policy, carbon emissions abatement by a limited coalition of countries can put energy-intensive production within the coalition at international competitive risk. Subglobal abatement provides scope for carbon leakage to the extent that emissions are relocated to countries outside the abatement coalition. The global distribution of economic adjustment costs to subglobal or unilateral emissions constraints is another source of concern in the context of intense international policy debate on fair burden sharing of climate protection. The perspective on how policy distortions are transmitted through international trade can have a profound influence on the validity of these concerns and thus the appropriate design of subglobal climate policy. In this paper we quantify the structural sensitivity of competitive effects, environmental outcomes (emission leakage), and the welfare implications triggered by subglobal emissions regulation. We assess the quantitative outcomes in the context of three important alternative international trade structures.

From an economic perspective, the efficiency rationale for international cooperation in controlling global environmental externalities such as CO_2 is straightforward—emissions should be reduced where it is cheapest to do so. International cooperation in the provision of a global public good such as climate protection, however, is hindered by severe incentive problems. In recent papers, for example, Libecap (2014) highlights the difficulty of assigning and enforcing property rights in international environmental agreements, and Nordhaus (2015) focuses on *free riding* as the primary impediment to international agreements on climate policy. The challenges of international cooperation have resulted in limited and uncoordinated action—to date. A group of developed countries are still motivated, however, to take a lead role in the battle against anthropogenic climate change.[1] Given the importance of international markets to environmental and distributional spillovers associated with subglobal action, a critical assessment of alternative perspectives on trade structures is indispensable.

The applied economic literature provides important insights into the interactions of emissions regulation and feedback effects from international markets. This literature relies heavily on Computable General Equilibrium (CGE) models, which are adept at translating policy shifts into economic responses based on microeconomic theory. Studies in this literature, however, overwhelmingly adopt a particular set of structural assumptions about international trade. More specifically, countries are assumed to produce regionally differentiated goods under perfect competition, and these imported and domestically produced differentiated goods are combined in a Constant-Elasticity-of-Substitution (CES) demand system.

The proposition to differentiate products by country of origin is often referred to as the Armington assumption, after its seminal notion and application by Armington (1969).[2] The Armington structure has several empirical advantages, but it has been criticized for its inconsistency with micro-level observations and questionable counterfactual implications. The Armington assumption provides a tractable solution to various problems associated with the standard neoclassical (Heckscher-Ohlin) perspective of trade in homogeneous goods [Whalley (1985)]: (i) it accommodates the empirical observation that a country imports and exports the same good (so called *cross-hauling*); (ii) it avoids over-specialization implicit to trade in homogeneous goods; and (iii) it is consistent with trade in geographically differentiated products. While the Armington assumption provides a convenient lens to view trade data,

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[1] The international community continues to negotiate on coordinated action through the United Nations Framework Convention on Climate Change (UNFCCC), including the upcoming Conference of the Parties session 21 (COP 21) scheduled for December 2015 in Paris France.

[2] The Armington assumption has also been used by theorists as a justifications for the *gravity* relationship observed in trade flows [e.g., Anderson (1979)]. Newer trade theories developed by Krugman (1980), Eaton and Kortum (2002), and Melitz (2003) naturally produce the same *gravity* relationship.

it may lead to unrealistically strong terms-of-trade effects that dominate the welfare results of policy changes [de Melo and Robinson (1989)].[3]

A striking example of the dominance of the Armington assumption in model-based climate policy analysis is provided by the recent Energy Modeling Forum study, EMF 29, which drew together 12 world-wide established CGE modeling groups to investigate the role of border carbon adjustments in unilateral climate policy.[4] In their overview article, Böhringer et al. (2012) point out that most models indicate significant shifting of abatement burdens to non-abating countries through terms-of-trade adjustments. The average ratio of the abatement coalition (Annex 1 except Russia) welfare cost to non-coalition welfare cost is 3:1 across models (under the reference scenario).[5] This result is surprising from the perspective of neo-classical trade since non-coalition manufacturing based economies face lower global energy prices and higher prices for their energy-intensive exports. It would seem that these direct impacts favoring comparative advantage in the non-coalition would outweigh the negative impacts of higher import prices of goods produced by the coalition. The reverse finding in the EMF 29 study is important because much of the policy debate centers on the neo-classical intuition. The findings of the EMF 29 study brings into question the idea that non-coalition countries can free ride on the abatement of the coalition. As we argue here, however, the EMF 29 results (as well as those obtained from the bulk of similar CGE applications) are critically dependent on the Armington perspective adopted in the underlying

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[3] Notable critiques on the implications of the Armington structure are offered by Kehoe (2005) and Brown (1987), while Melitz and Redding (2015) argue for the importance of micro-level structures.

[4] The Energy Modeling Forum (EMF) is organized by Stanford University (Professor John Weyant, Director) with a mission to communicate the results from alternative numerical models in the context of a carefully controlled comparison study (`https://emf.stanford.edu`).

[5] Relative to the reference scenario which is limited to uniform emission pricing of domestic fuel inputs, additional border adjustments on carbon embodied in trade significantly shift even more burden toward the non-coalition countries (Böhringer et al. (2012)).

models.[6]

In this paper we consider two alternatives to the Armington proposition and highlight the different evaluations of subglobal climate policy that are reached. The neo-classical perspective is captured by assuming a homogeneous-goods trade structure where energy-intensive goods (like iron and steel) are traded on world markets at a single price. Conclusions about changes in trade flows and the distribution of policy burdens are dramatically different relative to the Armington structure, even if the Armington trade elasticities are assumed to be very high. The empirical relevance of the homogeneous-goods model might be brought into question, however, because it only explains net trade abstracting from the observed gross trade (so called cross hauling). The other alternative to the Armington structure, the Melitz (2003) model of heterogeneous firms, preserves the basic neo-classical implications: larger shifts in the trade pattern, more leakage, and a dramatic shift in the policy burden away from non-coalition exporters of energy-intensive goods. Under the Melitz structure non-coalition exporters of energy-intensive goods enjoy a substantial welfare increase due to the competitive effects of coalition abatement. Furthermore, as predicted, exporters of energy-intensive goods are able to free ride on the abatement efforts of the coalition.

The remainder of the paper is organized as follows. In section 2, we present the three alternative international trade formulations and their calibration to empirical data. In section 3, we describe our climate policy scenario and discuss simulation results across the alternative model structures. In section 4, we conclude.

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[6] The one exception in EMF 29 is Balistreri and Rutherford (2012) who consider a Melitz structure as an alternative to Armington and find that non-coalition welfare might increase in the reference scenario. This observation prompted our deeper exploration, in this paper, of carbon policy and the structure of international trade.

2 Alternative Trade Model Formulations

In this section, we present three important alternative trade formulations that we adopt in our simulation analysis to study the implications of subglobal climate policy. First is a Heckscher-Ohlin model based on trade in homogeneous products, which establishes the traditional neoclassical view on comparative advantage. Second is a model based on regionally differentiated goods consistent with the Armington assumption, which is overwhelmingly adopted in the policy-simulation literature. Third is a monopolistic-competition model, following Melitz (2003), which is the focus of more recent international trade theories built around the micro-level observations of competitive selection and firm-level export behavior.

2.1 Heckscher-Ohlin (H-O) Structure

The Heckscher-Ohlin (H-O) trade structure operates on a simple set of arbitrage conditions for homogeneous goods. The set of goods of interest for the alternative structures in our empirical analysis is given by $i \in \{\texttt{CRP, NMM, I\_S, NFM}\}$, where:

`CRP`: Chemical, rubber, plastic products;

`NMM`: Non-metallic mineral products;

`I_S`: Ferrous metals; and

`NFM`: Non-ferrous metals.[7]

These represent the energy-intensive and trade-intensive industries which are most exposed to the competitive effects of unilateral climate policy. We will refer to the structure that treats these four goods (industries) as homogeneous tradables as the H-O model.

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[7] The selection of sectors and the choice of acronyms follow the classification adopted in our source data, GTAP 7 [Narayanan and Walmsley (2008)]. These data serve as the primary benchmark for our simulation analysis. More details on the data and calibration are provided in Section 2.4.

Homogeneity of traded goods is directly reflected in the arbitrage conditions for trade activities. Let a region's export activity for commodity i be given by EX_{ir} and its import activity be given by IM_{ir}. Let the price of good i in region r be given by c_{ir}, which equals the marginal cost of production under the standard H-O assumption of perfect competition. With an export tax rate of tx_{ir}, the export activity will satisfy the condition that the gross of tax marginal cost equals the world-market price (PW_i). Some export activities might be slack, however, indicating that the gross of tax marginal cost is at or above the world-market price. To accommodate this situation we represent arbitrage using the following complementary-slack condition:

$$c_{ir}(1 + tx_{ir}) - PW_i \geq 0 \quad \perp \quad EX_{ir} \geq 0. \tag{1}$$

where the $\perp$ symbol indicates the complementary slack relationship between the two expressions.[8] In words condition (1) reads as follows: if profitable, the export activity will intensify to the point that profits are driven to zero; if the export activity is unprofitable, exports will be zero. We have a similar arbitrage condition for regional import activities:

$$(PW_i + \sum_j \phi_{jir} PT_j)(1 + tm_{ir}) - c_{ir} \geq 0 \quad \perp \quad IM_{ir} \geq 0, \tag{2}$$

which is slightly complicated by the inclusion of transport margins. In condition (2) tm_{ir} is the import tariff rate, PT_j is the price of transport service j, and ϕ_{jir} are coefficients representing the cost markup paid to transport service j on the value of commodity i shipped to region r. Thus, in condition (2) arbitrage indicates that a region intensifies imports up to the point that the gross cost of importing equals the domestic marginal production cost. The

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[8] Mathematically our notation indicates the following three conditions embodied in (1): $c_{ir}(1 + tx_{ir}) - PW_i \geq 0$; $EX_{ir} \geq 0$; and $EX_{ir}\,(c_{ir}(1 + tx_{ir}) - PW_i) = 0$.

transport services include air, water, and other, which are denoted $j \in \{\texttt{ATP}, \texttt{WTP}, \texttt{OTP}\}$.[9]

We finalize our description of the H-O trade formulation with the market clearance conditions. The world market price for good i adjusts such that international markets clear:

$$\sum_r EX_{ir} = \sum_r IM_{ir}. \tag{3}$$

The trade activities are tied back to the domestic market through market clearance in the commodities that trade at c_{ir} within the region. Let Y_{ir} be the production quantity of good i in region r, and let Q_{ir} be the total of final and intermediate-input demand for good i in region r. Market clearance in region r of good i is then given by:

$$Y_{ir} + IM_{ir} - EX_{ir} = Q_{ir}. \tag{4}$$

Conditional on the endogenous variables determined in the broader general equilibrium (Y_{ir}, Q_{ir}, and PT_j), the four equations, (1) through (4), determine the variables, EX_{ir}, IM_{ir}, PW_i, and c_{ir}, that describe the H-O trade equilibrium. This system allows us to numerically apply the foundational neoclassical trade theory. One feature of this structure is that either the import or export activity will be slack in a given region for a given good under nontrivial trade cost. The model will thus not feature an equilibrium where a region both imports and exports the same good. Two-way trade, or *cross hauling*, is, however, observed in all trade data. To remedy this observation within our H-O structure we net out two-way trade from the gross flows, calibrating the H-O model to net trade only.

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[9] Other transport services, `OTP`, include road and rail. Again, the classification and notation for transport services refer to the GTAP database.

2.2 Armington Structure

The observation of two-way trade has motivated the proposition that goods under the same industrial classification from different countries are not identical. This is the Armington (1969) assumption of regionally differentiated goods. Under this structure two-way trade is readily accommodated. Countries demand both domestic and foreign varieties which are imperfect substitutes. Calibration to observed trade flows is simply a matter of establishing preference weights that match the benchmark observation. Responses to relative price changes are then controlled through the assumed elasticity of substitution—the so-called Armington elasticities.

The Armington assumption is a popular specification used in applied trade models. For the algebraic implementation, consider a composite commodity that is the Constant Elasticity of Substitution (CES) aggregate of domestic and foreign varieties. Denote the price of this composite in region s as P_{is}. We will refer to P_{is} as the Armington price index which is the minimized unit cost of the composite. Supply of the composite is governed by a competitive activity A_{is} that intensifies up to the point that marginal cost equals marginal revenue (given by P_{is}). In equilibrium we have:

$$P_{is} = \psi_{is} \left[\sum_r \theta_{irs} \left[(1 + tm_{irs})[c_{ir}(1 + tx_{ir}) + \sum_j \phi_{jirs} PT_j] \right]^{1-\sigma_i} \right]^{\frac{1}{1-\sigma_i}}, \tag{5}$$

where the right-hand side is the minimized unit cost (marginal cost) of the composite as a function of regional prices (c_{ir}), transport cost, and tariffs. Equation (5) is empirically operationalized by setting values for the scale and distribution parameters, as well as the elasticity of substitution, σ_i. The true price index of good i in region s is reflected in P_{is}, and this is the price paid for goods in intermediate or final demands. Market clearance for the composite good is given by:

$$A_{ir} = Q_{ir}. \tag{6}$$

Market clearance for regional output must now account for bilateral demand, which we denote X_{irs} (where r is the source region and s is the sink region):

$$Y_{ir} = \sum_{s} X_{irs}. \tag{7}$$

The X_{irs} are conditional demands derived by scaling the right-hand side of equation (5) up to a cost function (by multiplying by A_{is}) and applying Shephard's Lemma:

$$X_{irs} = \psi_{is} A_{is} \theta_{irs} \left[\frac{P_{is}}{(1 + tm_{irs})[c_{ir}(1 + tx_{ir}) + \sum_j \phi_{jirs} PT_j]} \right]^{\sigma_i}. \tag{8}$$

Conditional on the variables determined in the broader general equilibrium (Y_{ir}, Q_{ir}, and PT_j), the four equations, (5) through (8), determine the variables, A_{ir}, X_{irs}, P_{is}, and c_{ir}, that describe the Armington trade equilibrium.

2.3 Melitz Structure

Our third alternative trade specification follows Melitz (2003) and applies the notion of heterogeneous firms to energy-intensive tradable sectors. As in the H-O and Armington structures, let demand for the composite good in sector i and region r be given by Q_{ir} which includes intermediate and final demand. In this case, however, Q_{ir} is demand for the Dixit-Stiglitz composite of firm-level varieties from around the world. On the supply side we again have production of Y_{ir} which has a unit cost of c_{ir}. In the Melitz structure we consider this a composite input which is used by the monopolistically competitive firms to cover variable cost, as well as the sunk cost associated with establishing the firm, and the bilateral fixed cost associated with operating in a given bilateral market. The composite Q_{ir} (used in intermediate and final demand) is assumed to be made up of a continuum of firm varieties. Using the dual form, we specify the Dixit-Stiglitz price index for this composite commodity in region s (analogous to the Armington price index of regional varieties introduced in the previous section). Let $\omega_{irs} \in \Omega_{ir}$ index the differentiated i goods sourced from region r and shipped into region s. Let $p_{irs}(\omega_{irs})$ be the gross price of variety ω_{irs} and let σ_i, again, be the constant elasticity of substitution between the varieties. The price index is given by:

$$P_{is} = \left[\sum_r \int_{\omega_{irs}} [p_{irs}(\omega_{irs})]^{1-\sigma_i} d\omega_{irs} \right]^{\frac{1}{1-\sigma_i}}. \tag{9}$$

Melitz (2003) simplifies the price index by specifying the price of a representative firm from region r supplying market s. Denote this price $\tilde{p}_{irs}$ which is the gross price set by the firm engaged in exporting from r to s that has the CES-weighted average productivity. Using this price, and scaling it up by the measure of the number of firms, N_{irs}, operating on the r to s trade link, we obtain Melitz's simplified price index:

$$P_{is} = \left[\sum_r N_{irs} (\tilde{p}_{irs})^{1-\sigma_i} \right]^{1/(1-\sigma_i)}. \tag{10}$$

Notice that trade costs and tariffs do not enter equation (10), which is consistent with our definition of $\tilde{p}_{irs}$ as gross of these margins. Trade costs and tariffs will enter the optimal markup equation. The quantity supplied by the average firm must satisfy demand which is derived by applying Shephard's Lemma:

$$\tilde{q}_{irs} = Q_{is} \left(\frac{P_{is}}{\tilde{p}_{irs}} \right)^{\sigma_i}. \tag{11}$$

Consider a small profit-maximizing firm facing this demand. Consistent with the large-group monopolistic competition assumption, the *small* firm does not consider its impact on the aggregate price index (P_{is}). Now, let c_{ir} indicate the price of the composite i input in region r, and let $\tilde{\varphi}_{irs}$ indicate the productivity of the firm (such that the marginal cost of production is $c_{ir}/\tilde{\varphi}_{irs}$). Setting marginal cost equal to marginal revenue yields the optimal markup condition for the average firm:

$$\tilde{p}_{irs} = \frac{c_{ir}\tau_{irs}(1+t_{irs})}{(1-1/\sigma_i)\tilde{\varphi}_{irs}}, \tag{12}$$

where we introduce τ_{irs} as a calibrated trade-cost factor.[10] The ad valorem tariff rates are given by t_{irs}, as in the other trade formulations presented above.

To determine which firms operate in which market we need to identify the marginal firm (earning zero profits) in each bilateral market, and then relate the marginal firm to the average firm through a well specified productivity distribution. Let M_{ir} indicate the mass of region-r firms that are entered (in that they have incurred the sunk cost). These firms are assumed to receive their productivity draw from a Pareto distribution with probability density:

$$g(\varphi) = \frac{a}{\varphi}\left(\frac{b}{\varphi}\right)^a; \tag{13}$$

and cumulative distribution:

$$G(\varphi) = 1 - \left(\frac{b}{\varphi}\right)^a, \tag{14}$$

where a is the shape parameter and b is the minimum productivity. On each bilateral trade link there will be a productivity level φ^*_{irs} at which optimal pricing yields zero profits. A firm drawing φ^*_{irs} is the marginal firm. Firms drawing a productivity above φ^*_{irs} will earn positive profits and, therefore, operate. Firms drawing a productivity below φ^*_{irs} will choose

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[10] The τ_{irs} cost factors are a composite of observed payments to transport services, export-tax payments, and unobserved trade costs. Unobserved trade costs are introduced to facilitate a direct calibration to observed trade flows under the assumption of symmetric varieties in demand. Equivalently, we could reinterpret the unobserved portion of τ_{irs} as a calibrated idiosyncratic taste bias [see Balistreri and Rutherford (2013)]. In that case the unobserved portion of τ_{irs}, required to match the trade flows, act as quality adjustments to source-destination specific varieties that normalize the prices as they enter equation (10).

not to operate on the r to s link.

Denoting the fixed cost (in composite input units) associated with operating on the r to s link as f_{irs}, the marginal firm earns zero profits at:

$$c_{ir} f_{irs} = \frac{r(\varphi^*_{irs})}{\sigma_i(1 + t_{irs})}, \tag{15}$$

where $r(\varphi^*_{irs})$ is the revenue of the marginal firm which depends on the location of φ^*_{irs}. Following Melitz (2003), we refine the model by defining all of the conditions in terms of the average firm, rather than the marginal firm. To do this we need to relate the productivities and revenues of the average firm relative to the marginal firm in each market. Noting that there will be $N_{irs}/M_{ir} = 1 - G(\varphi^*_{irs})$ firms operating we can integrate over that portion of the Pareto distribution to find the CES weighted average productivity $\tilde{\varphi}_{irs}$ as a function of the marginal productivity:

$$\tilde{\varphi}_{irs} = \left[\frac{a}{a + 1 - \sigma_i}\right]^{\frac{1}{\sigma_i - 1}} \varphi^*_{irs}. \tag{16}$$

Given the firm-level demand and pricing conditions [equations (11) and (12)] we can establish the ratio of the revenues of the average to the marginal firm:

$$\frac{r(\tilde{\varphi}_{irs})}{r(\varphi^*_{irs})} = \left(\frac{\tilde{\varphi}_{irs}}{\varphi^*_{irs}}\right)^{\sigma_i - 1}. \tag{17}$$

Equations (16) and (17) allow us to represent (15) purely in terms of the average firm. This is the central zero-cutoff-profit condition that determines the number of firms operating in each bilateral market:

$$c_{ir} f_{irs} = \frac{\tilde{p}_{irs} \tilde{q}_{irs}}{(1 + t_{irs})} \frac{(a + 1 - \sigma_i)}{a \sigma_i}. \tag{18}$$

As the optimal markup condition depends on $\tilde{\varphi}_{irs}$ we need to determine this in equilibrium. Given a value of the fraction of operating firms $N_{irs}/M_{ir} = 1 - G(\varphi^*_{irs})$, we can solve for φ^*_{irs} and substitute it out of (16):

$$\tilde{\varphi}_{irs} = b\left(\frac{a}{a+1-\sigma_i}\right)^{1/(\sigma_i-1)}\left(\frac{N_{irs}}{M_{ir}}\right)^{-1/a}. \tag{19}$$

We now need to determine the measure of the total number of firms, M_{ir}. This is given by a free-entry condition that balances the sunk entry cost against the expected profits over the lifetime of the firm. Denote the sunk cost for region r in composite input units f^S_{ir}. Consistent with Melitz's steady-state equilibrium, a member of M_{ir} has some exit probability δ in every period. Then in the steady-state equilibrium δM_{ir} firms must be replaced each period at a total nominal cost of $\delta c_{ir} f^S_{ir} M_{ir}$. From the perspective of a given firm (with no discounting or risk aversion) the flow of expected profits would need to cover $\delta c_{ir} f^S_{ir}$. The expected profits in a given market are given by:

$$\tilde{\pi}_{irs} = \frac{\tilde{p}_{irs}\tilde{q}_{irs}}{\sigma_i(1+t_{irs})} - c_{ir} f_{irs}, \tag{20}$$

and the probability of operating in that market is N_{irs}/M_{ir}. The free-entry condition, that determines M_{ir}, equates expected profits across all markets with the sunk-cost payments:

$$c_{ir}\delta f^S_{ir} = \sum_s \frac{\tilde{p}_{irs}\tilde{q}_{irs}}{(1+t_{irs})}\frac{(\sigma_i-1)}{a\sigma_i}\frac{N_{irs}}{M_{ir}}, \tag{21}$$

where we have used the zero-cutoff-profit condition to substitute out the operating fixed cost. With this condition the heterogeneous-firms trade equilibrium is fully specified, but we still need a determination of demand for the composite input. The market clearance condition associated with c_{ir} must track the disposition of domestic output into the various sunk, fixed, and variable cost associated with each bilateral market. The market clearance condition is given as:

$$Y_{ir} = \delta f_{ir}^{S} M_{ir} + \sum_{s} N_{irs} \left(f_{irs} + \frac{\tau_{irs} \tilde{q}_{irs}}{\tilde{\varphi}_{irs}} \right). \tag{22}$$

Conditional on regional composite demand and composite-input supply (Q_{ir} and Y_{ir}), equations (10), (11), (12), (18), (19), (21), and (22) determine the full set of variables associated with the Melitz trade equilibrium. The corresponding variables are the composite price index (P_{is}); average-firm prices, quantities, and productivities ($\tilde{p}_{irs}$, $\tilde{q}_{irs}$, and $\tilde{\varphi}_{irs}$); measures of the number of entered and operating firms (M_{ir}, and N_{irs}); and the price of the composite input (c_{ir}).

2.4 Empirical Calibration

Apart from the alternative trade formulations the model is a standard multi-region multi-sector static representation of the global economy with detailed carbon accounting. We adopt the production structure outlined in Böhringer and Rutherford (2011) and calibrate the non-linear system of equilibrium conditions to an aggregated version of the GTAP 7 database.[11] Table 1 indicates the aggregate regions, sectors, and primary factors of production that we adopt for our evaluation of unilateral climate policy action.[12]

The trade equations are calibrated to match the benchmark trade flows. This is relatively straightforward in the Armington and Melitz models. The bilateral parameters for each commodity [either θ_{irs} in equation (5) or τ_{irs} in equation (12)] are set to replicate the bilateral trade matrix.[13]

For commodities modeled under the H-O structure the accounts are first adjusted to net

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[11] See Narayanan and Walmsley (2008) for a full documentation of the GTAP 7 database.

[12] The composite region of EUR compromises EU-28 and EFTA countries; the composite region of RA1 includes Australia, Belarus, Canada, Japan, New Zealand, Turkey, and Ukraine.

[13] See Balistreri and Rutherford (2013) for additional details and discussion about the methods for trade calibration in the Armington and Melitz models.

Table 1: Regions, goods, and factors in the empirical model

Regions:		**Goods:**		**Factors:**	
`EUR`	Europe	`OIL`	Refined oil products	`LAB`	Labor
`USA`	United States	`GAS`	Natural Gas	`CAP`	Capital
`RUS`	Russia	`ELE`	Electricity	`RES`	Natural Resources
`RA1`	Rest of Annex 1	`COL`	Coal		
`CHN`	China	`CRU`	Crude Oil		
`IND`	India	`CRP`	Chemical, rubber, plastic		
`EEX`	Energy Exporters	`NMM`	Non-metallic minerals		
`MIC`	Middle-High Income	`I_S`	Ferrous metals		
`LIC`	Low Income	`NFM`	Non-ferrous metals		
		`ATP`	Air Transportation		
		`WTP`	Water Transportation		
		`OTP`	Other Transportation		
		`AOG`	All other goods		

out gross trade, so equation (4) is satisfied with either imports or exports for a given region equal to zero.[14] Given balanced accounts, the global quantity produced of the homogeneous goods will still equal global demand (we just eliminate the value of any cross hauling). There remain a few subtleties, however. By moving to net trade we are significantly altering (reducing and sometimes eliminating) the tax base for ad valorem trade distortions along with the flows associated with the transport margins. This generates an imbalance in government revenues and demand for transport services. To reconcile the benchmark we push any residual export taxes, which are eliminated once we move to net trade, upstream into the source country market for the particular commodity. Similarly, we push any residual import tariffs, which are eliminated once we move to net trade, downstream into the destination market for the particular commodity. Assume, for example, that we originally observe a 10% tariff on \$100 of steel imports, but the trade flow drops to \$50 when we look at net trade; then

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[14] The slack trade activities are calibrated to be unprofitable based on the observed trade costs (taxes and transport margins). If, however, the trade costs do not generate at least a 5% margin of unprofitability on the slack activity, a 5% margin is inserted. This allows for trade reversals in counterfactuals, but does not generate trade reversals from trivial (less than 5%) changes in relative prices.

Table 2: Trade response parameters (σ_i unless otherwise noted)

	Armington			**H-O**	**Melitz**	
	Low	Central	High		σ_i	a_i
Energy-Intensive Tradables:						
CRP	3.30	5.58	11.16	∞	3.30	4.58
NMM	2.90	5.58	11.16	∞	2.90	4.58
I_S	2.95	5.58	11.16	∞	2.95	4.58
NFM	4.20	5.58	11.16	∞	4.20	4.58
Other goods:						
AOG	2.54	2.54	2.54	2.54	2.54	
CRU	∞	∞	∞	∞	∞	
COL	3.05	3.05	3.05	3.05	3.05	
GAS	11.48	11.48	11.48	11.48	11.48	
OIL	2.10	2.10	2.10	2.10	2.10	
ELE	2.80	2.80	2.80	2.80	2.80	
ATP	∞	∞	∞	∞	∞	
WTP	∞	∞	∞	∞	∞	
OTP	∞	∞	∞	∞	∞	

the new trade flow will only generate \$5 of revenue. To reconcile this, the commodity tax on steel in the destination market is escalated such that it generates an addition \$5 of revenue. This maintains the original \$10 of revenue for the government. The same adjustment is made for transport margins. The ad valorem transport margin is maintained, but to the extent that imports are reduced, the residual demand for transport services (needed to maintain market clearance) is added as a Leontief complement to destination regional demand for the commodity in question. The goal of this calibration strategy is to keep the trade margins (as ad valorem wedges) at the cost of manipulating domestic distortions and thereby maintaining consistency in ad valorem benchmark distortions across the alternative trade structures.

Calibration of the trade *responses* in the Armington and Melitz models warrants some additional remarks. Table 2 indicates the trade elasticities. For the energy-intensive goods we consider three different sets of values for the Armington elasticities. In the Low-Armington case we adopt the values from the GTAP database for substitution between imports and domestic goods. In the Central-Armington case we adopt $\sigma_i = 5.58$, which is consistent with the same local response indicated in a simple Melitz model with $a_i = 4.58$. The value of $a_i = 4.58$ is estimated by Balistreri et al. (2011), and the argument that σ_i should be set at $a_i + 1$ to replicate trade responses is given by Arkolakis et al. (2008). In the High-Armington case we take the suggested value and double it: $\sigma_i = 2(a_i + 1)$. All other sectors are held at consistent trade responses across the variations. Most of these values are adopted from the GTAP data. Crude oil is always treated as a homogeneous good, consistent with the estimates of σ_{CRU} in Balistreri et al. (2010a) of over 20. In addition, there is a composite transport good for each mode available on the world market. Each transport mode is specified as a Cobb-Douglas composite across the supplies from all regions.[15]

3 Policy Simulations and Results

We center our comparison of the alternative trade structures around an emissions abatement scenario that is widely studied in the numerical simulation literature on climate policies. The experiment entails CO_2 mitigation by a coalition of industrialized countries (Annex I Parties to the UNFCCC except Russia).[16] The global emissions target, to be achieved through emissions abatement in coalition countries, is set at benchmark global emissions less 20% of benchmark coalition emissions. The 20% abatement target for coalition countries roughly reflects the order of magnitude that various industrialized countries have stated as their unilateral emissions reduction objectives in official communications to the Framework Convention (see e.g. UNFCCC (2011)).

To the extent that unilateral emission regulation changes emissions outside the coalition,

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[15] Details of this standard formulation for international transport services in GTAP-based models are given in Böhringer and Rutherford (2011).

[16] A list of Annex I parties to the United Nations Framework Convention on Climate Change is available on line at: `http://unfccc.int/parties_and_observers/parties/annex_i/items/2774.php`. We include the United States of America in the coalition but exclude Russia, which is consistent with scenarios adopted in the EMF 29 study.

we adjust the nominal emission reduction target by the coalition countries endogenously to adjust for carbon leakage. By holding the global emission level constant across the different model variants we assure a meaningful comparison of economic adjustment costs independent of an estimate of the benefits of CO_2 emissions abatement.[17] Our central measure of economic adjustment costs is regional (Hicksian) equivalent variation in income.[18]

Table 3 presents the percentage equivalent variation for the abatement scenario across the different trade structures. One immediately apparent result is that, relative to the Armington structure, both the H-O and Melitz structures indicate elevated coalition costs of achieving the global emissions reduction. These elevated costs for the H-O and Melitz structures are the result of higher leakage and, in the case of the Melitz structure, an adverse productivity impact in the coalition. With higher leakage, the coalition must scale up domestic abatement efforts to meet the prescribed global target. In the absence of the Armington assumption on energy intensive goods, coalition countries are also less able to tip the terms of trade in their favor via emissions regulation.[19] Under the Melitz structure the elevated costs of emissions regulation in the coalition are amplified through productivity losses in energy-intensive sectors. Faced with abatement costs high-productivity marginal exporting firms retreat to the domestic market, which drags down industry-wide productivity.

The non-coalition welfare impacts across structures are of considerable interest as these are in the focus of international policy debates on burden sharing. The Armington structure indicates substantially more shifting of the policy burden onto non-coalition regions. We highlight these impacts in Figure 1. While the regions heavily dependent on energy

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[17] For simplicity we assume that environmental benefits, which accrue to the regional agents, is directly related to total global abatement, and that the environmental benefit is separable in welfare.

[18] Hicksian equivalent variation in income denotes the amount of money that is necessary to add to, or deduct, from the benchmark income of the regional agents so that they enjoy a utility level equal to the one in the counterfactual policy scenario, on the basis of ex-ante prices.

[19] With regional product heterogeneity, emissions pricing works as a substitute for an optimal tariff, shifting part of the economic adjustment cost from abating regions to non-abating regions (see Krutilla (1991) and Anderson (1992)), and it is well documented that the Armington structure generates high optimal tariffs even for small countries (see Brown (1987) and Balistreri and Markusen (2009)).

Table 3: Regional welfare impacts of reference scenario across trade structures (% Equivalent Variation (EV))

Region	Cons. ($B)	Change (%EV) **Armington**	**H-O**	**Melitz**
Coalition				
`USA`	8267	-0.18	-0.57	-0.66
`EUR`	8075	-0.40	-0.74	-0.83
`RA1`	3914	-0.43	-0.78	-1.41
Non-Coalition				
`MIC`	2330	0.01	0.65	1.79
`EEX`	848	-4.34	-2.65	-1.17
`CHN`	796	-0.15	0.89	0.43
`IND`	434	0.73	1.26	0.81
`LIC`	349	-0.67	-0.10	0.28
`RUS`	292	-6.07	-3.22	-1.92

exports (`EEX` and `RUS`) experience negative impacts regardless of the trade structure, these impacts are smaller under H-O or Melitz trade.[20] There is considerably more opportunity for non-coalition countries to take advantage of competitive opportunities in energy-intensive production under the H-O and Melitz structures, which mitigates the negative impact of lower fuel prices on welfare. Essentially, coalition abatement favors a movement of production location upstream. Energy exporters can replace energy exports with exports of energy intensive goods, but the Armington structure limits these opportunities.

The differences across structural assumptions are even more pronounced for those non-coalition economies that are manufacturing based. As a prime example, under the Armington structure China faces a slight welfare loss. While China benefits from lower international fuel prices and higher demands for its energy-intensive exports, it experiences a dominating adverse terms-of-trade shift under the Armington structure as imports of coalition varieties

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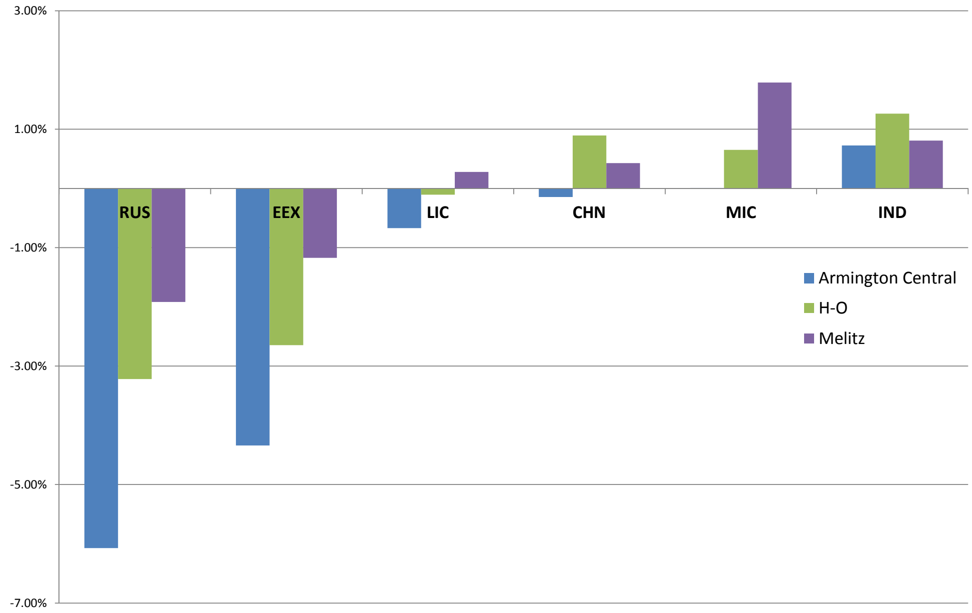
[20] A robust channel of welfare impacts across all three trading structures, are terms of trade effects on fossil fuel markets. The reduction of global demand for fossil energy associated with the targeted decline of global emissions depresses international fuel prices which induces revenue losses for fuel exporters and cost savings for fuel importers.

Figure 1: Non-coalition burdens across trade structures (% Equivalent Variation)



become more costly and real incomes fall. In contrast, under the H-O structure we show substantial gains for China when the coalition engages in CO_2 mitigation. China's energy-intensive industries expand and trade patterns adjust such that China is better off under unilateral climate policy, an outcome which is in line with the wide-spread idea that non-coalition countries can *free ride* on the abatement efforts of the coalition. We also find substantial gains for middle-income countries under the H-O trade structure (which are not available under Armington), and even more accentuated gains for middle-income countries under the Melitz structure.

In Figure 2 we convert the non-coalition welfare changes into *money-metric* measures. This allows us to aggregate welfare effects across regions.[21] Focusing on the total non-coalition money-metric welfare changes we can see the dramatic impact our alternative structural assumption have on conclusions about policy burdens. Under the Armington

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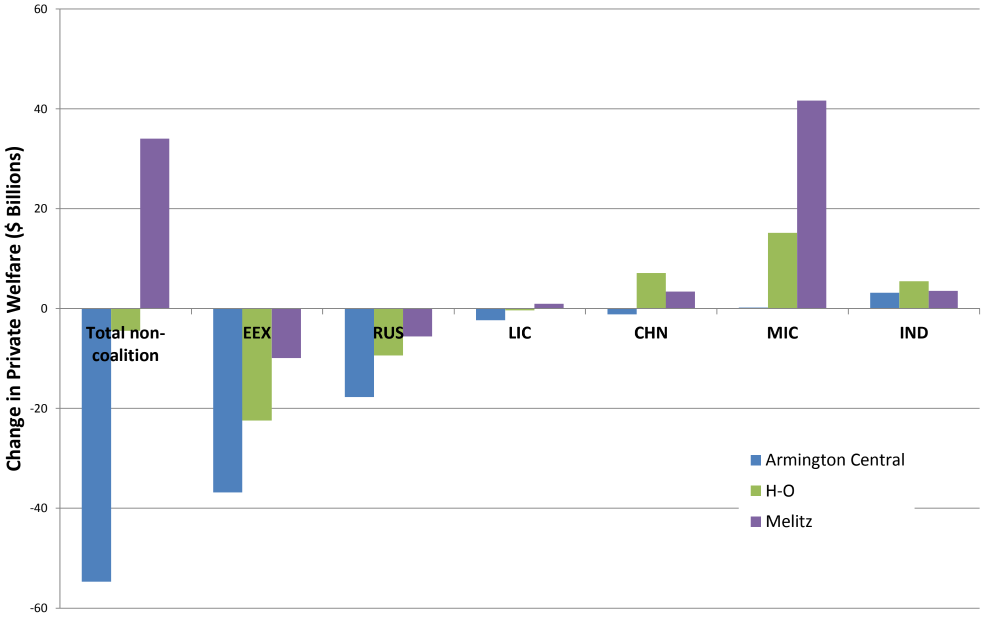
[21] We adopt a utilitarian perspective where dollar-for-dollar welfare changes of individual regions are perfectly substitutable.

Figure 2: Non-coalition burdens across trade structures (Money Metric $B)



structure the burden on non-coalition regions is measured to be about $55 billion (1.1% of benchmark consumption) and under the H-O structure this drops to less than $5 billion. Given the productivity changes under the Melitz structure the policy burden is reversed, and we measure a $35 billion welfare increase for the non-coalition countries in total.

The results indicate that one's perspective on which trade structure holds has substantial implications for the international climate policy debate. The dramatic shifts in policy burdens illustrated in Figure 2 indicate that, without taking a stance on the "correct" structure, we are uncertain of even the qualitative nature of the economic impacts for non-coalition countries.

The substantial differences in welfare impacts across structures are largely driven by differences in the predicted global reallocation of energy-intensive production. Table 4 and Figure 3 show the changes in regional production of energy-intensive goods.[22] The most

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[22] Output is stated in value (price times quantity) where prices are measured relative to the weighted average of the regional consumer price indexes. That is, we use the consumption-weighted average of the

dramatic shifts in output away from the coalition countries is seen under the H-O structure (a loss of \$238.8 billion in sales), closely followed by the Melitz structure (a loss of \$190.7 billion in sales). In contrast, demand for the unique regional Armington varieties are maintained, such that we only see a \$78.1 billion loss in coalition sales of energy-intensive goods. Production of energy-intensive goods increases in the non-coalition regions in response to the competitive advantage that coalition abatement affords. Again this response is sensitive to the structural assumptions, with the most limited response under Armington. It is informative to track the global change in the value of energy-intensive production (shown in the final row of Table 4). Relative to the Armington structure, there is little change in the value of energy-intensive goods produced under the H-O and Melitz structures. Again, the indication is that there is significant hysteresis with regional Armington varieties. With perfect substitute products (H-O) or firm-level varieties (Melitz) the general equilibrium shows substantially more locational redistribution of energy-intensive production in response to subglobal climate policy.

The global redistribution of energy-intensive production translates into changes in the trade equilibrium. Table 5 shows the changes in the values of energy-intensive exports by region, and Table 6 provides a decomposition of these results into the effects on each of the four energy-intensive commodities. Note that the first columns in Tables 5 and 6 indicate benchmark trade flows under the H-O structure, and the second columns indicate the actual benchmark trade flows used as the benchmark for the Armington and Melitz structures. These benchmark flows are different because the H-O model operates on net trade and cannot accommodate observed cross hauling. While the H-O model starts from a smaller set of benchmark flows, the perfect substitutes formulation indicates changes in trade flows that are in the range of magnitudes shown under the Melitz structure, and are much larger than the changes indicated under the Armington structure. It is interesting to note that under

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regional true-cost-of-living indexes as the global numeraire.

Table 4: Changes in the value of energy-intensive output ($B)

		Change ($B)		
	Benchmark	**Armington**	**H-O**	**Melitz**
Coalition	3861.8	-78.1	-238.8	-190.7
`USA`	1084.0	-32.2	-123.6	-70.2
`EUR`	1819.5	-20.6	-59.7	-49.1
`RA1`	958.3	-25.4	-55.5	-71.4
Non-Coalition	2263.5	51.4	228.6	186.1
`MIC`	823.8	19.8	63.6	80.8
`EEX`	204.5	14.1	55.9	59.7
`CHN`	967.2	2.8	44.7	6.6
`IND`	118.7	1.3	11.6	0.9
`LIC`	47.1	2.0	16.1	7.4
`RUS`	102.2	11.3	36.7	30.8
Global	6125.3	-26.7	-10.2	-4.5

Figure 3: Energy-intensive production across trade structures ($B)

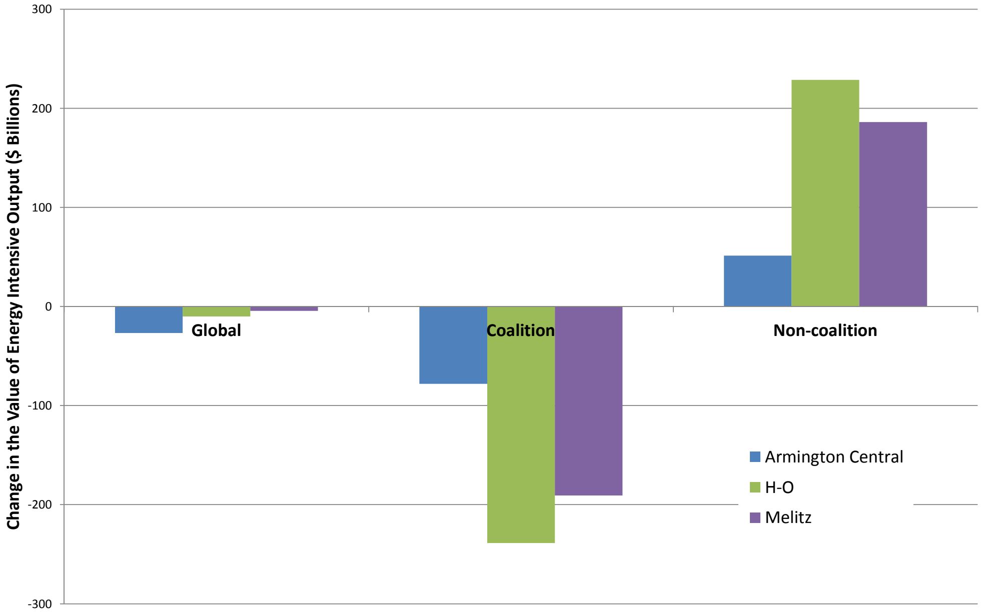

Table 5: Changes in the value of energy-intensive exports ($B)

			Change ($B)		
	Benchmark (H-O)	Benchmark	**Armington**	**H-O**	**Melitz**
Coalition	132.1	641.2	-31.6	-82.6	-73.0
`USA`	6.0	178.9	-13.0	-6.0	-26.0
`EUR`	89.3	262.0	-7.1	-39.7	-15.7
`RA1`	36.8	200.2	-11.6	-36.8	-31.3
Non-Coalition	54.5	427.1	27.9	98.8	113.2
`MIC`	12.2	200.9	7.9	18.2	43.3
`EEX`	0.4	70.7	7.4	16.6	33.5
`CHN`	6.5	79.8	2.9	25.7	7.8
`IND`	1.6	18.8	0.8	7.9	1.4
`LIC`	2.8	11.1	0.9	2.9	4.5
`RUS`	31.0	45.7	8.0	27.5	22.7
Global	186.6	1068.3	-3.8	16.2	40.2

Armington the global value of trade in energy-intensive goods is actually reduced. The substantial reduction in coalition exports of energy-intensive goods is not offset by increases in non-coalition exports. The H-O and Melitz models on the other hand show that subglobal climate policy intensifies the use of international markets in energy-intensive goods.

In Table 6 the details of the trade equilibrium are revealed. Notice first that moving to net trade under the H-O structure substantially changes the benchmark. For example, we see that Russia is the only non-coalition region that is a net exporter of chemical, rubber, and plastic products. Moving to net trade reduces non-coalition exports of chemical, rubber, and plastic products from $234.7 billion to $2.2 billion in the benchmark! This is an unappealing adjustment in the data, and it highlights the challenge of bringing the traditional theory to the data. The Armington structure is immediately appealing as a solution to this challenge, but looking at the changes in exports we see substantial hysteresis in the pattern of trade. While the Armington structure might perform well local to the benchmark, it fails to represent significant disruptions in the pattern of trade. The Melitz structure with firm-level differentiated products, in contrast, is both able to accommodate the observed pattern of trade and can show responses to structural shocks that dramatically change the pattern of trade. For example, we see very small changes in iron and steel exports under the Armington structure, but under the Melitz structure there are major shifts in the pattern of trade. Under Armington, middle-income countries respond to coalition abatement by increasing iron and steel exports by \$2.9 billion (an 8% increase), where as under the Melitz structure they ramp up iron and steel exports by \$32.0 billion (a 93% increase). Critically, both structures are parameterized to generate the same local trade response (the Armington elasticity is set equal to the Pareto shape parameter plus one). Similar local responses do not translate to the same policy impacts when the structures are different.

One might consider the differences observed between the Armington and Melitz structures and conclude that the Armington parameterization might be modified to better approximate trade and productivity responses.[23] To explore the sensitivity of the Armington structure to alternative parameterizations we present the welfare impacts of the abatement scenario for low, central, and high values of the Armington elasticity of substitution between regional varieties (see Table 2 for the various trade response parameters).

In Table 7 we see a relatively continuous departure from the central results when we vary the Armington elasticities. This indicates that one cannot simply reparameterize the Armington model to replicate the Melitz results. At the extreme of an elasticity of substitution equal to infinity the Armington structure should be consistent with a H-O theory. The problem with exploring this limit is that the Armington structure calibrated to gross

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[23] Arkolakis et al. (2008) and Arkolakis et al. (2012) show a set of equivalence results indicating that the Armington structure can be parameterized to replicate the trade responses and welfare impacts of the Melitz structure. The conditions for equivalence are difficult to meet in an empirical simulation model of climate policy, however. Examples of the restrictions that would be difficult to reconcile with an empirical application include a single sector economy (or trivially symmetric multiple sectors) with one factor of production and no intermediate inputs. It is relatively easy to break the equivalence results once we move away from the sterile theoretic models. See Balistreri et al. (2010b), Costinot and Rodríguez-Clare (2015), and Melitz and Redding (2015) for additional discussion of the equivalence results.

Table 6: Detailed energy-intensive trade responses (Exports $B)

			Change ($B)		
	Benchmark (H-O)	Benchmark	**Armington**	**H-O**	**Melitz**
		CRP: Chemical, rubber, plastic products			
Coalition	84.5	445.6	-18.0	-34.9	-28.8
USA	6.0	145.2	-9.8	-6.0	-19.0
EUR	77.5	191.8	-3.8	-27.9	-5.4
RA1	1.0	108.7	-4.4	-1.0	-4.5
Non-Coalition	2.2	234.7	9.6	9.5	32.1
MIC		114.4	1.7		-0.9
EEX		47.2	4.5		22.1
CHN		44.7	0.6		4.0
IND		11.2	0.3		0.5
LIC		3.5	0.3		0.7
RUS	2.2	13.8	2.2	9.5	5.6
Global	86.7	680.3	-8.4	-25.4	3.2
		NMM: Non-metallic mineral products			
Coalition	9.6	35.8	-2.2	-9.6	-2.5
USA		7.1	-0.7		-1.2
EUR	7.6	17.0	-0.8	-7.6	-0.8
RA1	1.9	11.7	-0.7	-1.9	-0.4
Non-Coalition	7.2	26.4	2.3	27.2	4.6
MIC		9.8	1.0		1.8
EEX		3.8	0.4		0.7
CHN	6.5	10.2	0.7	25.7	1.7
IND	0.7	1.3	0.1	1.5	0.2
LIC		0.7	0.1		0.1
RUS		0.6	0.1		0.1
Global	16.8	62.2	0.1	17.6	2.2
		I_S: Ferrous metals			
Coalition	25.6	77.6	-6.9	-25.6	-27.0
USA		10.3	-0.9		-1.7
EUR	4.2	26.8	-1.6	-4.2	-5.4
RA1	21.4	40.5	-4.5	-21.4	-19.9
Non-Coalition	14.8	74.1	8.4	21.1	46.8
MIC		34.3	2.9		32.0
EEX		6.7	0.9		3.6
CHN		12.1	0.9		0.8
IND	0.8	4.1	0.3	6.4	0.6
LIC		1.1	0.1		0.5
RUS	13.9	15.8	3.1	14.7	9.3
Global	40.4	151.7	1.5	-4.5	19.8
		NFM: Non-ferrous metals			
Coalition	12.5	82.1	-4.6	-12.5	-14.7
USA		16.3	-1.7		-4.1
EUR		26.5	-0.8		-4.1
RA1	12.5	39.4	-2.1	-12.5	-6.4
Non-Coalition	30.3	92.0	7.6	41.0	29.8
MIC	12.2	42.6	2.3	18.2	10.4
EEX	0.4	13.1	1.5	16.6	7.1
CHN		12.8	0.6		1.4
IND		2.3	0.0		0.0
LIC	2.8	5.8	0.5	2.9	3.1
RUS	14.8	15.4	2.7	3.3	7.8
Global	42.8	174.1	3.0	28.5	15.1

Table 7: Armington model sensitivity to the choice of Armington elasticities (% Equivalent Variation)

	Cons.	**Armington**		
Region	($B)	Low	Central	High
Coalition				
`USA`	8267	-0.11	-0.18	-0.29
`EUR`	8075	-0.36	-0.40	-0.48
`RA1`	3914	-0.35	-0.43	-0.56
Non-Coalition				
`MIC`	2330	-0.14	0.01	0.26
`EEX`	848	-4.68	-4.34	-3.77
`CHN`	796	-0.23	-0.15	0.02
`IND`	434	0.70	0.73	0.78
`LIC`	349	-0.71	-0.67	-0.57
`RUS`	292	-6.70	-6.07	-5.12

trade flows becomes unstable relative to the H-O model, which is calibrated to net trade flows. In the High-Armington case (where the elasticity of substitution is set above 11 for the energy-intensive goods) we do not see a substantial convergence between the Armington and H-O models, although the welfare changes in the High-Armington case are all between the central and H-O cases. For example, the percent equivalent variation for China is -0.15 for the Central-Armington case, 0.02 for the High-Armington case, and 0.89 for the H-O case. Overall, even when we set the Armington elasticities at extreme values relative to the empirical literature, we find substantial differences across structures.

Carbon leakage refers to a major concern on the global environmental effectiveness of unilateral emissions abatement. In Table 8 we compare the leakage rates across structures. The leakage rate is defined as the change in foreign non-coalition emissions over coalition emissions reduction. A leakage rate of 50%, for instance, means that half of the coalition emissions reduction is offset by increases in non-coalition countries.

Leakage rates are highest under the H-O structure at 23.5% and lowest under the Arm-

Table 8: Carbon leakage rates (%) across trade structures

	Armington			**H-O**	**Melitz**
	Low	Central	High		
Total	**13.4**	**14.9**	**17.3**	**23.5**	**21.8**
Decomposed by non-coalition region					
`MIC`	5.0	5.2	5.6	5.2	7.2
`EEX`	2.3	2.8	3.6	5.3	5.8
`CHN`	2.3	2.5	2.8	4.7	2.3
`RUS`	1.5	2.0	2.7	4.2	4.0
`IND`	1.2	1.3	1.4	2.0	1.1
`LIC`	1.0	1.1	1.2	2.0	1.3

ington Low-elasticity case at 13.4%. The differences across trade structures largely reflect the implied reallocation of energy-intensive production across the globe. Consistent with Table 4 and Figure 3 we see the highest leakage rates when there is more movement of energy-intensive production to non-coalition regions through the competitive-effects channel. Also consistent with the production results, notice that under the H-O structure China plays a much larger role in leakage and under the Melitz structure leakage is dominated by the middle-income region. Given the initial base in energy-intensive manufacturing the middle-income countries move resources into energy- and trade-intensive sectors under the Melitz structure, whereas under the H-O structure China specializes and in particular dominates the international market for non-metallic mineral products (see Table 6).

4 Conclusion

In this paper we explore the sensitivity of conclusions about the impact of unilateral climate policy to alternative perspectives on the structure of international trade. We adopt three compelling structures for trade in energy-intensive goods. First is a Heckscher-Ohlin structure based on trade in homogeneous products consistent with standard neoclassical trade theory. Second is the Armington structure of trade in regionally differentiated goods, which is widely adopted for numerical policy simulations. Third is the Melitz (2003) structure of monopolistic competition among heterogeneous firms producing unique varieties. We investigate the implications of these structures for the evaluation of economic impacts induced by subglobal climate policy. We find significant differences in economic impacts across these structures and highlight the sensitivity of policy conclusions.

Under the Heckscher-Ohlin and Melitz structures substantially larger shifts in the pattern of trade are recorded, relative to the Armington structure. Larger shifts in the pattern of trade go along with significantly higher carbon leakage rates as a source of concern on the global environmental effectiveness of subglobal abatement action. We caution that studies adopting the Armington structure might be understating the competitive effects and carbon leakage associated with subglobal emissions abatement. Even with artificially inflated trade elasticities the Armington model generates lower leakage rates than the other two models.

With respect to the international climate policy debate on burden sharing, our most important finding is that the empirically appealing Melitz structure indicates a qualitative change in the welfare impacts for countries outside the abatement coalition. Competitive effects in the Melitz structure are intensified by productivity changes. We find that the Melitz structure indicates welfare increases in the non-coalition countries that export energy-intensive goods. This is in contrast to the Armington model, which predicts welfare losses due to a terms-of-trade deterioration. The Armington model thereby seems out of line with the mainstream policy intuition. Lower energy costs and higher prices for energy-intensive exports are expected to boost welfare in the non-coalition manufacturing economies. Our paper shows that this expectation is supported in the Melitz structure, but not in the Armington structure. We see our implementation of the Melitz structure as an important innovation that deserves consideration in applied simulation analysis of climate policy helping to place decision making on a more informed basis.

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