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Structural Estimation of a Flexible Translog Gravity Model*

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Abstract

How large are the gains from trade? Do all trade models have the 'same old gains'? Arkolakis, Costinot, and Rodriguez-Clare (2012) show that many quantitative trade models that summarize trade responses via a single elasticity have the same welfare implications. I develop a flexible approach to estimating trade responses using a translog expenditure function, and find welfare results that differ starkly from conventional trade models. In my model, trade responses can vary bilaterally, and the link between own- and cross-price elasticities of trade to trade cost is broken. I apply my approach to inter-regional trade flows in North America and international trade flows between OECD and BRICS countries. I structurally estimate the parameters and conduct counterfactual analyses. Canada's border effect is at least three times smaller than estimates in previous literature. Compared to those implied by the formula in Arkolakis et al., welfare responses are larger and more heterogeneous. The welfare losses from raising trade barriers are underestimated by eight times for China, France, India, and the United Kingdom, and underestimated by more than ten times for Australia, Brazil, Canada, and Russia.

Keywords: Gravity model, Translog expenditure function, Structural estimation, Gains from trade.

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1 Introduction

A central question in international economics is how best to measure the gains from trade. The workhorse tool to measure the welfare gains is the empirical gravity model of trade. There is a wide variety of theoretical models that provide a foundation for the gravity model and interpret empirical patterns of bilateral trade[1]. These theoretical models have many different motivations for trade, but recent work by Arkolakis, Costinot, and Rodriguez-Clare (2012) has shown that a broad class of quantitative trade models have equivalent implications for the welfare gains from trade[2]. Among other common features, all these models summarize trade responses via a *single* elasticity. This elasticity also summarizes both the own- and cross-price responses of trade to changes in trade costs[3].

The use of a single parameter to summarize trade responses is an assumption of convenience, not necessity. The single parameter simplifies theoretical calculations and provides applied researchers with a parsimonious framework for estimating trade responses. But trade responses to geographic frictions can vary across importers, suggesting that a more flexible approach to estimation may be preferable. I develop a flexible approach that allows trade responses to vary bilaterally. This approach also breaks the link between own- and cross-price elasticities of trade to trade costs. As a result, the welfare responses are different from other quantitative trade models.

The flexible approach augments a standard gravity model with a more flexible demand system, by representing the expenditure function with a translog form. In general, the translog form does not impose any *a priori* restrictions on elasticities. Novy (2012) derives and estimates a gravity model that uses the translog form, but he does so in a context that leaves many strengths of the translog form unexploited. In order to estimate the gravity equation using ordinary least squares (OLS), Novy restricts the translog form so as to generate a single structural parameter that can be recovered from the data. While own- and cross-price effects differ in his framework, they do so by a constant multiple — the substitution matrix contains a single value along the diagonal and a single value off the diagonal. This parsimony implies that the translog form, under the estimating restrictions Novy imposes, is also restricted so as to imply the same welfare implications as other

[1]Examples include Anderson (1979) and Krugman (1980) to more recent works by Anderson and Van Wincoop (2003), Eaton and Kortum (2002), and Melitz (2003).

[2]Arkolakis et al. (2012) restrict their analysis to trade models that satisfy three macro-level restrictions: trade is balanced, profits are a constant share of GDP, and the import demand system is CES.

[3]The own-price elasticity of trade is the elasticity of imports with respect to variable trade costs as it characterizes the response of import demand to its own price. The cross-price elasticity of trade is the substitution elasticity between goods as it describes the response of import demand to the price of other goods.

gravity models (Arkolakis et al., 2010).

In contrast, my work follows the Diewert and Wales (1988) approach to fitting a semi-flexible version of the translog form. This approach offers sufficient flexibility to generate a rich substitution matrix. The restrictive substitution pattern imposed elsewhere in the literature is a permitted special case but importantly is not imposed at the outset. Indeed my empirical results suggest that a richer substitution matrix than is assumed in the simpler models is an important feature of the data. An added bonus of my approach is that both the theory and the estimating model allow zero trade flows[4], and these zeroes can be directly included in the estimation.

The estimation technique involves the solution of a mathematical program with equilibrium constraints (MPEC) as proposed by Judd and Su (2011). This structural estimation has the benefit of ensuring full theoretic consistency. It also allows a straightforward and transparent link between the estimating model and the counterfactual model[5]. Some papers have applied the MPEC approach to estimate general equilibrium models of bilateral trade (Balistreri and Hillberry, 2007; Balistreri, Hillberry, and Rutherford, 2011), but those papers estimate trade models with a single elasticity. I extend these methods to estimate a translog gravity model.

I estimate the model on two data sets: (i) inter-regional flows between Canada and the U.S. used by Anderson and Van Wincoop (2003), and (ii) international flows between OECD and BRICS countries from the UN COMTRADE. My empirical results suggest a rich substitution pattern in the bilateral trade data. Given this rich substitution pattern, the theoretical link between a given trade shock and welfare that is the basis of Arkolakis et al. (2012) no longer holds. I conduct theory-consistent counterfactual exercises and find smaller border effects than in previous literature. I also find much larger and more heterogeneous welfare responses than are implied by Arkolakis et al. (2012). The intuition for the different results is that the translog form requires larger implied trade costs to account for missing trade because trade responses of the large bilateral flows are smaller than in the CES case.

In the first counterfactual analysis, I re-examine the border puzzle through the lens of the translog gravity model and find smaller border effects compared to estimates in the literature. In the seminal study, McCallum (1995) finds that Canada has a border effect of 20: the border causes trade between Canadian provinces to be 20 times larger than cross-border trade with the U.S.

[4]Anderson and van Wincoop (2004), Haveman and Hummels (2004), and Helpman, Melitz, and Rubinstein (2008) have highlighted the prevalence of zeroes in bilateral trade flows and suggested theoretical interpretations for them.

[5]See Balistreri and Hillberry (2008) for a discussion of this issue in the context of the Anderson and Van Wincoop (2003) gravity model.

Anderson and Van Wincoop (2003) show that McCallum's border effects are overestimated because variables capturing the effects of relative prices on trade flows were excluded. While Anderson and Van Wincoop estimate smaller border effects than McCallum, they are still large: Canada has a border effect of 10.5 while the U.S. has a border effect of 2.6. Balistreri and Hillberry (2007) provide a methodological contribution by estimating the border effects in a theory-consistent way[6]. They find a border effect of 7.6 for Canada and 4.9 for the U.S. Compared to the estimates in previous literature, I estimate smaller border effects: Canada has a border effect of 2.5 and the U.S. has a border effect of 2.

In the second set of counterfactual analyses, I examine the welfare loss from more restricted trade by (i) raising the import barriers of each OECD and BRICS country, and (ii) increasing the trade barriers of China. Not surprisingly, all countries lose from more restricted trade but the welfare losses are larger and more heterogeneous than implied by the welfare result in Arkolakis et al. (2012). They show that their formula, henceforth called the ACR formula, can calculate the welfare effects of trade shocks for a broad class of quantitative trade models. The formula establishes a linear relationship between a country's expenditure on its home goods and the own-price elasticity of imports. By allowing for varying elasticities in the translog model, this relationship no longer holds. The counterfactual calculations show that the ACR formula greatly underestimates the welfare effects of increasing trade restrictions. The average welfare loss of increasing one's trade barrier is 26 percent according to the counterfactual calculations and 2 percent according to the formula calculations. The welfare responses are also more heterogeneous than implied by the formula. The range of welfare losses from increasing trade barriers is 4.7 to 32.9 percent in the counterfactual calculations and only 2.1 to 3.0 percent in the formula calculations.

The key distinction of the translog model is that trade responses are not summarized by a single elasticity parameter, and allows trade responses to vary bilaterally. But how reasonable is this feature of the model? Despite different motivations for trade, many theoretical models use a single structural parameter to govern the responsiveness of trade to changes in trade costs[7]. Even though this is a parsimonious framework for estimation, it may be unrealistic to assume that every country has the same trade responses, regardless of country size and distance to market. When

[6]As noted in Balistreri and Hillberry (2007), their method of conducting the counterfactual analysis is preferable to that used by Anderson and Van Wincoop (2003) because regional incomes can change when the border is removed.

[7]Anderson (1979) and Bergstrand (1985) assume an Armington product differentiation based on country of origin to derive their gravity equations. Subsequent studies introduced more complex production structures to the gravity model: monopolistic competition (Bergstrand, 1989); Heckscher-Ohlin (Deardorff, 1998); a multi-product and multi-country Ricardian model based on Dornbusch, Fischer, and Samuelson (1977) (Eaton and Kortum, 2002); and heterogeneous firms (Melitz, 2003 and Helpman, Melitz, and Rubinstein, 2008).

trade costs change, changes in relative prices will affect the demand for a good and its substitutes. But a single elasticity implies that import demands change at the same percentage.

In order to illustrate variability in trade responses, I regress the log of shipments on bilateral distances and home consumption dummy variables in a fixed effects model. The regression is a gravity-like equation, but I include an interaction term between the distance variable and the importer dummy variable to capture the possibility of different elasticities for each importer. The data are inter-regional shipments between Canada and the U.S. from Anderson and Van Wincoop (2003). The data and variables are discussed further in Section 4.

The results in table 1 show that each importer has a different trade response. The interaction terms, included in column 3, do not change the standard relationship that exists between bilateral shipments, distances and home consumption. An F-test on the joint significance of the interaction terms fails to reject the null hypothesis, indicating that at least one importer has a different distance coefficient. The distance coefficients do not, however, directly inform us whether there are different own-price elasticities. From the theoretical models, the distance coefficient is identified as a product of two parameters: the distance elasticity of trade costs and the own-price elasticity of imports. But if we assume that each importer has the same distance elasticity, which is plausible since we are examining inter-regional shipments within two countries, we can attribute the different distance coefficients to different own-price elasticities of imports.

The remainder of the paper is organized as follows. The flexible approach is developed in Section 2, and compared to Novy (2012). Section 3 describes the structural estimation method and identification strategy. Section 4 re-examines the border puzzle in Canada and the U.S. It describes the inter-regional data, empirical results, and border effect estimates. Section 5 explores the effects of higher trade restrictions. It details the international data, empirical results, and welfare responses to higher trade barriers. Section 6 concludes.

2 Model

The model assumes an Armington model where consumers are identical in their preferences over the goods differentiated by origin (Armington, 1969)[8]. Let there be $n = 1, ..., N$ countries, and each country is endowed with an amount of a good that is differentiated by country of origin. Each country consumes N number of goods, including its own, but the consumption amount is

[8]The Armington assumption facilitates parsimonious estimation and allows a direct comparison to the results in Anderson and Van Wincoop (2003).

non-negative and can vary across countries. Iceberg trade costs reduce this consumption. The representative consumer maximizes a utility function subject to a budget constraint and generates an import demand.

The utility maximization problem can be expressed as its dual, the unit expenditure function. The unit expenditure function is equal to the consumer price index, or the true cost-of-living index, and provides the amount of expenditure needed to obtain one unit of utility. The unit expenditure function can be represented using a translog functional form. The translog expenditure function introduced by Diewert (1976) is a second-order approximation of an arbitrary expenditure function. Flexible functional forms, like the translog form, do not impose any restrictions but are still consistent with the assumptions inherent in the approximated functions[9].

I assume that the unit expenditure function is a translog specification with respect to prices. Using n, k to index the goods, the translog expenditure function is defined as:

$$\ln E_j \quad = \quad \xi + \sum_{n=1}^{N} \alpha_n \ln \tilde{p}_{nj} + \frac{1}{2} \sum_{n=1}^{N} \sum_{k=1}^{N} \beta_{nk} \ln \tilde{p}_{nj} \ln \tilde{p}_{kj} \tag{1}$$

with these restrictions

$$\sum_{n=1}^{N} \alpha_n = 1, \ \sum_{k=1}^{N} \beta_{nk} = 0, \ \beta_{nk} = \beta_{kn} \ \forall n, k = 1, ..., N \tag{2}$$

imposed to fulfill homogeneity and symmetry conditions. The parameters in the translog function are analogous to those in the CES unit expenditure function. The α_n parameters are the preference weights for country n's goods, and the β_{nk} parameters inform us about the substitutability between goods n and k.

The destination price $\widetilde{p}_{nj} = p_n \tau_{nj}$ is the trade-cost inclusive price of good n in country j, where p_n is the free-on-board (f.o.b.) price of good n, and τ_{nj} is the costs of trading the goods between countries n and j. Trade cost is assumed to be an iceberg cost where τ_{nj} is the amount of good required to ship one unit of the good from n to j, i.e. $\tau_{nj} > 1, \ \forall \, n \neq j$, otherwise $\tau_{jj} = 1$.

Expenditure functions are concave in prices and this property is achieved in the translog expenditure function if the Hessian matrix is negative semidefinite, i.e. the second order partial

[9] Arkolakis et al. (2012) and Feenstra (2010) demonstrate that the single elasticity parameter models have similar welfare implications, regardless of whether the gains are demand-side (consumer) or supply side (producer) gains. The parameter flexibility introduced here on the demand side in the expenditure function may not produce the same welfare gains if flexibility is introduced on the supply side.

derivatives with respect to prices $\nabla_{p_{nj}p_{kj}} E_j$ are negative semidefinite[10]. The concavity property is maintained in the translog expenditure function by imposing the restrictions from Diewert and Wales (1988) in the estimation, which will be discussed in Section 3.

Applying Shephard's Lemma to equation (1), the import share equation can be derived as:

$$s_{ij} = \frac{x_{ij}}{m_j} = \alpha_i + \sum_{n=1}^{N} \beta_{in} \ln \tilde{p}_{nj} \tag{3}$$

where s_{ij} is the share of country i's goods in country j's income (m_j), and $x_{ij} = q_{ij}\tilde{p}_{ij}$ is the nominal value of country j's imports from country i. In the CES model, the import demand share equation is:

$$s_{ij} = \frac{x_{ij}}{m_j} \quad = \quad \left(\frac{\theta_i \tilde{p}_{ij}}{E_j} \right)^{1-\sigma}, \tag{4}$$

where σ is the constant elasticity of substitution parameter and θ_n is the taste parameter for country n's good.

In many empirical gravity models of trade, welfare effects can be summarized by the ACR formula. Arkolakis et al. (2012) show that welfare effects of changes to trade costs can be captured with just two statistics, the change in the expenditure on the home good and the own-price elasticity of imports:

$$W_j = 1 - \left(\frac{\lambda_{jj}}{\lambda'_{jj}} \right)^{1/\varepsilon} \tag{5}$$

where λ_{jj} and λ'_{jj} are the country's expenditure on the home good at the old and new equilibrium after the changes in trade costs, and ε is the elasticity of imports with respect to trade costs. In the CES model, the own-price elasticity of imports is $\varepsilon^{CES} = 1 - \sigma$. Thus, the welfare effects from changes in trade costs will have a linear relationship with changes in openness $\left(\frac{\lambda_{jj}}{\lambda'_{jj}} \right)$. These two parameters are sufficient for welfare analysis in these models because openness reflects the change in traded goods and the elasticity is the change in the quantities due to changes in prices (Imbs and Mèjean, 2011).

With a translog expenditure function that implies variable elasticities, welfare effects can no longer be summarized by the ACR formula. For their result to hold, the model must have an

[10]It is a common issue that the curvature conditions of theoretical functions are not satisfied by the estimated functional forms. Restrictions can be placed on the function to impose global concavity but this might remove the flexibility of the translog form (Diewert and Wales, 1987). Alternatively, concavity can be achieved while maintaining flexibility in the translog form by imposing local restrictions at a chosen reference point (Ryan and Wales, 2000).

important macro-level restriction — a CES import demand system. Such an import demand system means that the bilateral imports between two countries are only affected by changes to trade costs on that bilateral link. In this context, it means that the elasticity of bilateral imports between countries i and j with respect to their trade costs is given as:

$$\varepsilon^{CES} = \frac{d \ln x_{ij}}{d \ln \tau_{ij}} = 1 - \sigma, \tag{6}$$

while the elasticity of bilateral imports with respect to trade costs on another bilateral link (for example, countries k and j) is zero, i.e. $\frac{d \ln x_{ij}}{d \ln \tau_{kj}} = 0$ where $i \neq k$.

The translog gravity model trade between countries i and j is affected by trade costs between countries k and j. The model is more flexible than the CES import demand system, which can be easily shown by taking the derivative of the import demand shares:

$$\varepsilon_{ik}^{Trans} = \frac{d \ln x_{ij}}{d \ln \tau_{kj}} = \frac{\beta_{ik}}{s_{ij}} \geq 0. \tag{7}$$

As trade costs increase along the k-j link, country j can substitute away from the goods of country k and increase its imports from country i.

Arkolakis et al. (2010) show that the ACR formula can summarize welfare changes in a model with translog preferences, but they obtain this result by applying restrictions on the translog form in Feenstra (2003). The difference between the translog models is that the one discussed in this paper uses country-level varieties, while the others uses firm-level varieties. Novy (2012) has a gravity model with translog preferences, where he applies the restrictions in Feenstra (2003). These restrictions impose structure on the preferences and create a CES-like structure. A check of the gravity equation in Novy shows that it conforms to a CES import demand system. Thus, although Novy deviates from the CES preferences, his model will have the same welfare implications as the quantitative trade models. These restrictions are not used in this paper and therefore welfare effects cannot be summarized by the ACR formula.

The different welfare result in the translog gravity model can be attributed to the varying elasticities for each bilateral pair. As each exporter sells at the same f.o.b. price, the different destination prices are due to differences in trade costs. Thus the elasticity of imports with respect to trade costs is essentially the own-price elasticity of trade flows, while the elasticity of substitution between goods is the cross-price elasticity, which measures (in relative terms) the demand responses of a good due to changes in the price of another good. With CES preferences, *both* the own-price and cross-price elasticities of imports are determined by the constant elasticity of substitution parameter. A consumer in these models alter his demand in the same manner to any price changes whether it is the price of the good or a substitute. A single elasticity is not supported by the data as shown in table 1.

In the translog gravity model, the link between the own-price elasticity of imports and substitution elasticity is broken: the own-price elasticity is no longer related to the cross-price elasticity. The substitution elasticity between goods in the translog model can be calculated using the Allen elasticity of substitution. The Allen elasticity between goods i and j is the change in the relative quantity consumed due to a one percent change in the relative prices. From Berndt (1991), the formula for the Allen elasticity between two goods is given as:

$$\sigma_{ij} = \frac{\beta_{ij} + s_{ij}s_{jj}}{s_{ij}s_{jj}} \;\; \forall i, j \text{ and } i \neq j, \tag{8}$$

while the own elasticity of substitution (i.e. with its own prices) equals:

$$\sigma_{ii} = \frac{\beta_{ii} + s_{ii}^2 - s_{ii}}{s_{ii}^2}. \tag{9}$$

A positive elasticity indicates that the goods are substitutes where an increase in the price of good i will increase the demand for good j. Given empirical estimates of β_{ij} and fitted $\hat{s}_{ij}$, the elasticities can be easily calculated.

The own-price elasticities in the translog gravity model are not common and symmetric between bilateral pairs. The own-price elasticity of imports can be derived from equation (3) as:

$$\varepsilon_{ij}^{Trans} = \frac{d \ln x_{ij}}{d \ln \tau_{ij}} = \frac{\beta_{ii}}{s_{ij}}. \tag{10}$$

The own-price elasticity depends on β_{ii}, a parameter capturing the exporter's preference for the home goods, and s_{ij}, the exporter's market share in the importing country. As the β_{ii} parameter is specific to each exporter and the market shares are different for each bilateral pair, the elasticity will be unique and asymmetric for each pair. The parameter estimates of β_{ii} and predicted import shares will replace β_{ii} and s_{ij} in the calculation of the elasticities.

The elasticities in the translog model is different from those in Novy (2012). While Novy has a model with firm-level varieties, he uses an measure of extensive margin to simplify the estimation.

The own-price elasticity of imports in his model is:

$$\varepsilon_{ij}^{Novy} = \frac{d \ln s_{ij}}{d \ln \tau_{ij}} = -\frac{\gamma g_i}{s_{ij}} \tag{11}$$

where g_i is a measure of extensive margins of the exporting country taken from data, and γ is a parameter from the restrictions Novy places on the translog function. It may not be suitable to use this measure given that it implicitly assumes each country is exporting the entire product range to every country. Whereas the numerator in equation (10) is an estimated parameter that varies with exporters, the numerator in this own-price elasticity varies only by the extensive margin[11].

The own-price elasticity of imports derived in this paper gives a nuanced description of trade responses. It captures the tension between how much of a good is consumed at home and how much of it is consumed in foreign markets. The β_{ii} parameter summarizes an exporter's preference for its home good, which determines how much it exports. The market share (s_{ij}) describes the consumption share of the good in the importing country. The own-price elasticity of imports also capture the effects of distance and country size on trade flows through the market share parameter. If the exporter is near the destination market, the short distance will lessen trade costs and keep the destination prices low. Similarly, if the exporter is a large country, it can sell the good at a low f.o.b. price because a substantial home market can produce economies of scale. Although scale economies are absent in the model, they are present in the data and the model may pick up this feature in the estimation. Lastly, if the importing country is small, an exporter is more likely to capture a sizable market share. In these three cases, the exporter's market shares will be large, indicating that these trade flows are relatively inelastic.

For example, Australia is a large and relatively open country that exports about 75 percent of its production. It can command a large market share in the New Zealand market because that market is close-by and small. Therefore, New Zealand's demand for Australian imports will be relatively inelastic. Conversely, Australia will only capture a small percent of the U.S. market because of the distance and sheer size of that market. The U.S. demand for Australian imports will then be relatively elastic. In the CES model, New Zealand and the U.S. react in the same fashion to an increase in trade costs and decrease its imports from Australia by the same proportion.

The own-price elasticity of imports also captures aspects of market competition. An exporter

[11] Novy develops his model assuming monopolistic competition. In a model with Armington goods, the extensive margin measure will be absent in equation (11) and variation in the elasticities depend solely on the import share values.

that is a large seller in a market will face less competition and have a more inelastic demand in that market. Conversely, for an exporter that is a small seller, the competition is higher and there is a more elastic demand for its goods. Relative to an exporter with a small market share, an increase in trade costs will have a smaller impact on an exporter with the larger market presence because it can pass on the higher trade costs to the consumers[12].

3 Estimating Framework

3.1 Structural Estimation

The choice of estimation method depends on how we impose the model's structure in estimation. As Anderson and Van Wincoop (2003) show, excluding structure can create omitted variable bias in the estimation. In particular, they show that applying market clearance conditions on the trade model introduces inward and outward multilateral resistance terms into the import demand equation, capturing the effects of relative prices. The multilateral resistance terms are a function of each other and trade cost variables, which introduces non-linearity in the estimation. Several methods are used to deal with this issue, with fixed effects and non-linear estimation being the two most common[13]. With fixed effects methods, the multilateral resistance terms are assumed to be constant and replaced with country-specific or bilateral fixed effects. With non-linear estimation methods, the multilateral resistance terms, together with the gravity equation, are estimated jointly as a system of equations.

Alternatively, the market clearance conditions can be applied directly as constraints in the estimation. Balistreri and Hillberry (2007) develop a method to do this and estimate a CES gravity model with Armington assumptions. This method is essentially the MPEC approach discussed in Judd and Su (2011), which guarantees full theoretic consistency of the fitted values and the estimated parameters[14]. It also allows a simple transition to the counterfactual analyses, which is discussed later. It has also been used to estimate a model with monopolistic competition and heterogeneous firms (Balistreri et al., 2011).

The estimating strategy in Balistreri and Hillberry (2007) is to minimize the squared differences

[12] Edmond, Midrigan, and Xu (2012) examine this insight with a richer model that includes firm activities. They derive an elasticity of imports with respect to trade costs that depends on the import shares in an industry and the reallocation of expenditure between industries.

[13] There is a recent empirical method developed by Baier and Bergstrand (2009) that uses a first-order Taylor-series expansion of the multilateral resistance terms to estimate the system of gravity equations.

[14] The MPEC is used to solve a Walrasian general equilibrium here whereas the focus of MPEC estimation has been on partial equilibria, and more typically Nash equilibria.

between the observed (z_{ij}) and fitted ($\hat{z}_{ij}$) values of the import share[15]:

$$\min \sum_i \sum_j \left[z_{ij} - \hat{z}_{ij} \right]^2 . \tag{12}$$

The minimization problem is subjected to constraints implied in the model: a market clearance condition where a country's income is spent on all imports; an income equation that relates real and nominal income; a unit expenditure function that measures the cost of living; and a utility equation that describes utility levels. While the market clearance condition impose model structure on estimation, the income equation, unit expenditure function, and utility equation insure full theoretical consistency of the fitted general equilibrium. Full consistency in estimation is important for subsequent counterfactual analysis (Balistreri and Hillberry, 2008).

I adapt this estimation framework to the translog model. First, the fitted values of the import share are defined according to the derived import share demand in equation (3). Second, the translog unit expenditure function in equation (1) is used. Third, the market clearance condition is modified to use the fitted import share values. The constraints are:

$$y_i = p_i m_i \quad \forall i, \tag{13}$$

$$m_i = \sum_j \hat{s}_{ij} m_j \quad \forall i, \tag{14}$$

$$\ln E_j = \xi + \sum_{n=1}^{N} \alpha_n \ln \tilde{p}_{nj} + \frac{1}{2} \sum_{n=1}^{N} \sum_{k=1}^{N} \beta_{nk} \ln \tilde{p}_{nj} \ln \tilde{p}_{kj} \quad \forall j, \tag{15}$$

$$U_i E_i = y_i \quad \forall i. \tag{16}$$

Equation (13) defines the income of a country where y_i and m_i are the real and nominal income of the country i. Equation (14) defines clearance in the goods market. Equation (15) is the unit expenditure function, and equation (16) defines the utility of country i where U_i is the utility level. These conditions are like in Balistreri and Hillberry (2007), except they use a CES unit expenditure function in equation (15).

In order to estimate the parameters, additional constraints are needed. The GE model is

[15] The structural estimation approach is set out in the appendix of Balistreri and Hillberry (2007).

normalized such that observed nominal income equals the real income:

$$y_i = m_i \quad \forall i, \tag{17}$$

$$p_i = 1 \quad \forall i. \tag{18}$$

The constant term in the unit expenditure function (ξ) is assumed to equal one[16]. The homogeneity and symmetry restrictions from equation (2) are also imposed in the estimation. To ensure that monotonicity conditions are met, further restrictions are placed on the predicted import shares such that it is between zero, and one and the sum of the shares in each importer sums to one:

$$0 \leq s_{ij} \leq 1 \quad \forall i, j \tag{19}$$

$$\sum_{j}^{N} s_{ij} = 1. \tag{20}$$

As the import shares sum to one, an import share equation is dropped, otherwise the variance-covariance matrix is singular. Choice variables in the estimation are the coefficients in the import share equation (α_n and β_{nk}) and the general equilibrium variables (U_i, p_i, c_i and y_i). The non-linear estimation is solved in the GAMS software using the CONOPT algorithm.

For purposes of comparison, I also estimate a CES gravity equation with the same method. The logarithm of the import shares are used, and the fitted value in the minimization problem (12) is defined by taking the log of import demand in equation (4):

$$\ln s_{ij} = \ln m_j + (1 - \sigma) \left[\ln \theta_i + \ln p_i + \ln \tau_{ij} - \ln P_j \right]. \tag{21}$$

Changes are made to the expenditure function and market clearance conditions to reflect those in the CES model. [17]The importer income coefficient is also restricted to one to be consistent with theory (Balistreri and Hillberry, 2007). The CES specification estimates the values of σ and θ_i, conditional on the trade cost specification.

[16]The ξ parameter is a common scalar across all countries and will shift the expenditure functions in the same way. Assuming that $\xi = 1$ reduces the number of parameters to be estimated in the system and does not have any implications on the results. This is also consistent with how a CES unit expenditure function will be expressed. Drawing an analogy with the CES unit expenditure function, the α_n parameters are analogous to the weights in the CES function; the β_{nk} substitution parameters to the elasticity of substitution; and that means that ξ in equation (1) is the scalar in the CES function, which equals one.

[17]The CES expenditure function is defined as $E_j = \left[\sum_n^N (\theta_n \tilde{p}_{nj})^{1-\sigma} \right]^{\frac{1}{1-\sigma}}$, and the market clearance conditions are $m_i = \sum_j x_{ij} \ \ \forall i$.

A key difference between the translog and CES formulations, and the advantage of using the translog model, is the possibility of having zeroes in the dependent variable. With the CES specification, the dependent variable (s_{ij}) is in logarithm form and zeroes complicate the estimation and inference. There are many strategies used in the literature to deal with zeroes: exclude them from the estimation, add a small value to the zeroes, or use the pseudo-Poisson maximum likelihood approach set out by Santos Silva and Tenreyro (2006). With the translog model, we can include the zeroes in the estimation.

Trade cost is assumed to be a multiplicative function of distance and home consumption: $\tau_{ij} = dist_{ij}^{\rho} \exp(\delta)^{1-home_{ij}}$ where $dist_{ij}$ is the distance between country i and country j; ρ is the distance elasticity of trade cost; $home_{ij}$ is a dummy variable capturing home consumption where $home_{ij} = 1$ if the country is consuming home goods; and $\exp(\delta)$ is the ad valorem tax for crossing national borders.

Standard errors are calculated using bootstrapping techniques for all the variables in the estimation and counterfactual analyses. For each iteration, a new bootstrap sample is drawn with replacement from the original sample. The process is repeated 1,000 times.

Structural estimation of this sort facilitates counterfactual analysis in a straightforward manner. The model used in counterfactual analysis is that which appears in the constraints. Equations (13) to (16) impose constraints on the estimation method to create an operational GE model. In the estimation stage, income and prices are fixed and variables in the model are estimated. In the counterfactual stage, the structural estimates are locked in while income and prices are freed up for the counterfactual analysis. Changes are made to the general equilibrium model to reflect the counterfactual scenarios, and the new equilibrium is solved. The percentage changes to income, prices and utility are calculated by comparing the changes from the baseline trade equilibrium to the counterfactual equilibrium levels.

3.2 Identification Strategy

Estimation of gravity models in international trade is usually concerned with identifying a single parameter — the elasticity of imports with respect to trade costs. The single parameter models sometimes require additional assumptions to be made in the theoretical model. For example, Melitz (2003) introduces firms with heterogeneous productivity levels in his model, but keeps the distribution of productivity levels general. By assuming a Pareto distribution of productivity levels, applied researchers create a parsimonious model to estimate a single elasticity parameter.

While the translog form allow us to move away from estimating a single elasticity parameter, there is an challenge of separately identifying the variables in the trade cost specification and the import demand equation. This challenge is common in the estimation of CES models and is not unique to the translog model. When the trade cost specification is substituted into the import demand equation, the unknown variables in trade costs (ρ and δ) interact with those in the import demand equation: $(1-\sigma)$ in the CES specification and β_{nk} in the translog specification.

Since there is not enough information in the data to separately identify the parameters, a value for one parameter can be chosen to help with identification. Anderson and Van Wincoop (2003) assume a value for σ post-estimation. Balistreri and Hillberry (2007) impose the value $\sigma = 5$ pre-estimation but this is without consequence to the results. Since the translog model does not contain the σ parameter, it makes more sense to impose a value for ρ in our estimation. Given their value of $\sigma = 5$, it implies that the distance elasticity of trade cost in the North American data is $\rho = 0.36$. I impose this value before estimation, which allows us to be consistent with Anderson and Van Wincoop (2003) and Balistreri and Hillberry (2007). Similarly for the OECD and BRICS data set, I impose a value of $\rho = 0.267$ before estimation. This value is taken from Hummels (2001) because it is a direct estimate of the distance elasticity of trade cost from freight costs data. The value is also used in Novy (2012).

In the translog expenditure function, the own-price elasticity of imports is no longer restricted to be a single structural parameter. This flexibility, however, introduces complexities into the estimation process. Estimating the full translog specification with the parameter restrictions to ensure homogeneity and symmetry is equivalent to estimating $\frac{N(N+1)}{2} + N + 1$ parameters: one δ parameter, N a_n parameters, and $\frac{N(N+1)}{2}$ β_{nk} parameters. If there are 50 goods in the sample, the 2500 observations are used to estimate 1326 parameters. The degrees of freedom and the efficiency of parameter estimates are greatly reduced compared to the CES specification.

Novy (2012) adopts the restrictions in Feenstra (2003) to reduce the parameters in the substitution matrix. He has a model with firm-level varieties and the translog expenditure function has G goods. The restrictions in Feenstra (2003) severely restrict the β_{nk} parameters in the substitution matrix to depend on a single parameter (γ) and the total number of goods (G):

$$\beta_{nk}^{Novy} = \frac{\gamma}{G}, \quad \forall n \neq k \tag{22}$$

$$\beta_{nn}^{Novy} = -\frac{\gamma}{G}(G-1). \tag{23}$$

The substitution matrix in Novy includes only two values: one along the diagonal (23) and one off the diagonal (22). These restrictions place an *a priori* assumption on the substitutability of the goods. With the same off-diagonal elements, it presupposes that each good is a substitute to every other good. It will be better to allow the data to inform us about the substitutability of the goods.

Novy also implicitly assumes that each country exports the same number of goods to every trade partner. This assumption allows him to use a measure of extensive margins to further reduce the number of parameters to be estimated. The restrictions and assumption help achieve parsimony in the model, but it is overly restrictive and essentially returns us to a single parameter model. In his model, Novy is estimating the value of γ. Although Novy starts with a model of monopolistic competition, the restrictions and assumption also simplifies the model in such a way that aggregate trade flows can be used. A fixed effects model is estimated with aggregate trade flows between 28 OECD countries.

An alternative set of restrictions developed by Diewert and Wales (1988) might be a better approach to reduce the number of parameters in the substitution matrix. These restrictions create a semi-flexible functional form, which is suited to deal with large numbers of goods in translog specification. The form maintains some degree of flexibility while still being consistent with the concavity assumptions required for the expenditure function.

Diewert and Wales (1988) decompose the $N \times N$ substitution matrix, $B \equiv [\beta_{nk}]_{N \times N}$, into the product of a lower triangular matrix and its transpose:

$$B = -DD^T \tag{24}$$

where D is a lower triangular matrix of rank $r \leq N-1$ chosen by the econometrician. They prove that the D matrix exists, and the semi-flexible functional form can approximate a differentiable function up to the second order. Relative to the fully flexible translog form, the number of parameters to be estimated is greatly reduced. For example, choosing a rank one lower triangular matrix reduces D to an $N \times 1$ vector, and if $N = 50$, only 101 parameters need to be estimated instead of 1326 parameters in the fully flexible translog form. The restrictions also constrain the substitution matrix to be a negative semidefinite matrix, which ensures that the expenditure function is concave in prices.

The semi-flexible functional form has been successfully used to estimate translog demand systems with many goods. Kohli (1994) demonstrates that the cost of using the semi-flexible functional form is small while the benefits of increased efficiency are large. He does not find large differences in the elasticities calculated with a low rank matrix compared to a higher rank matrix. Neary (2004) uses this approach to estimate a Quadratic Almost Ideal Demand and an Almost Ideal Demand systems. He begins his estimation with a rank one matrix and uses the results as the starting value for the rank two matrix. Neary continues this process to estimate the full rank substitution matrix. While that is an innovative way to apply the Diewert and Wales approach, Neary (2004) estimated the elasticities for eleven goods. His approach will be difficult to implement given the large number of goods considered in this paper.

Instead, I use a rank one decomposition developed by Kee et al. (2008). They apply the Diewert and Wales approach to estimate the import demand equations for 4,900 goods. They reparameterize the substitution matrix by imposing these constraints:

$$\beta_{nk} = \gamma b_n b_k, \quad \forall n \neq k \tag{25}$$

$$\beta_{nn} = -\gamma b_n \sum_{n \neq k} b_k, \tag{26}$$

where γ, b_n, and b_k are constants. The reparameterization reduces the translog function to be flexible of degree one. The constraints also satisfies the symmetry constraints: $\beta_{nk} = \beta_{kn}$, and the homogeneity constraints: $\sum_{k \neq n} \beta_{nk} + \beta_{nn} = 0$.

4 Re-examining the Canadian-U.S. Border Puzzle

The first empirical exercise is performed on the North American data. With this data set, it will be easy to understand the implications of using the translog model as opposed to the CES model. The own-price elasticity of imports, the border taxes, and the resulting border effects of the U.S. and Canada from the translog gravity model are compared to the CES gravity model.

4.1 Data

The full details on the data are in Anderson and Van Wincoop (2003), so just a summary of the data is provided here. The data consists of trade flows between 10 Canadian provinces, 30 U.S. states, and a region called Rest-of-U.S., which aggregates the other 20 U.S. states, in 1993. The trade and income data are collected from Statistics Canada, the U.S. Census and the U.S. Bureau of Economic Analysis. Distance is calculated as great circle distances and normalized by the shortest distance pair (Maryland-Maryland). The normalization ensures that there is no iceberg melt on the shortest route, and iceberg melt increases as distance increases[18]. The home consumption variable is constructed to capture trade flows that do not cross national borders: $home_{ij} = 1$ for inter-provincial or inter-state trade flows. There are 69 zeroes in the trade flows that are excluded in the CES estimation, but included in the translog estimation, which explains the different sample sizes in the results table.

The dependent variable (s_{ij}) is constructed by taking the ratio of imports from region i (x_{ij}) and expenditure of region j (m_j). A region's expenditure is the total amount spent on all imports, and is usually the income of the region. There is, however, a discrepancy between the expenditure of a region, measured as the value of total imports, and the region's income. This can occur, for example, because of the presence of non-traded service sectors. The discrepancy between expenditure and income figures is an issue in any estimation of the gravity model, but it becomes more important here[19]. In the translog estimation, the shares of an importing region should equal one, which allows us to drop a share equation. If income is larger than expenditure, the total import shares will not equal one. The solution taken in this paper is to create an artificial measure of expenditure by aggregating the import values and treating that as the region's expenditure.

4.2 Estimation Results

As a benchmark, the CES model is first estimated using the import demand equation (4) together with the GE constraints in equations (13) to (16). The results replicate those in Balistreri and Hillberry (2007), and are presented in column 1 of table 2. Conditional on the value of the distance elasticity of trade cost ($\rho = 0.36$), the estimate for the own-price elasticity $(1 - \sigma)$ is -4, and the estimate for δ is 0.46, which implies that there is a 58 $[= \exp(0.46) - 1]$ percent ad valorem tariff if the region is importing from beyond national borders. These estimates are significant at the five percent level based on bootstrapped standard errors.

The estimates of α_n and β_{nn} are presented in table 3. The value of the α_n indicates the weight of the regions in the expenditure function, and it is clear that the larger regions dominate. Other than Rest-of-U.S., which will naturally have a large weight, the top five regions are California,

[18] Iceberg melt refers to the fraction of the good that "melts" away on the trade route, much like how an iceberg will melt if shipped across that route. Normalizing the distances does not affect the equilibrium as the coefficients are invariant to scale. As pointed out by Balistreri and Hillberry (2006), the scale is important if we are concerned about how much melt occurs on the trade route.

[19] Anderson and Van Wincoop (2003) face this issue in their estimation, but they did not impose an aggregation constraint. The MPEC method requires consistency with all the conditions of the model, including aggregation conditions, so I will take a stand on domestic trade flows.

Texas, and New York from the U.S., and Ontario and Quebec from Canada. The estimates for the diagonal elements of the substitution matrix (β_{nn}) indicate a region's substitution preference for its own goods versus the foreign goods. Most of the α_n and β_{nn} estimates are significant at the five percent level or lower, except Florida and Missouri.

The estimates of the average own-price elasticity of imports and the border tax in the translog estimation, presented in column 2 of table 2, are close to the CES estimates. The average own-price elasticity of imports for the 1662 bilateral pairs with positive import shares is $\overline{\varepsilon_{ij}} = -6.39$. The estimate obtained for δ is 0.55, which is a 73 $[= \exp(0.55) - 1]$ percent ad valorem tariff for consuming foreign goods.

The elasticities are calculated using estimates of β_{nn} and s_{nj}. Predicted market shares are used because observed values may not lie on the fitted curve, which will bias the elasticity estimates. Using fitted values in elasticity calculations is the common practice in demand system estimation with the translog functional form. Novy (2012) uses the observed data in his elasticity calculations instead of using the predicted values from his estimation[20].

The average ε_{ij} conceals a full distribution of estimated bilateral own-price elasticities of imports. In the translog model, how a country responds to a change in trade cost depends on the strength of the substitution to the home goods (β_{nn}) and the market share of the exporting country (s_{nj}). Figure 1 presents the distribution of 1662 bilateral own-price elasticities, with a median elasticity of -2.53. Over 65 percent of the bilateral pairs have elasticities above CES elasticity estimate of -4, and most pairs (over 95 percent) have elasticities larger than -20. There is a long left tail in the elasticity distribution where the exporters have very small market shares, which imply that these import demands are more sensitive to changes in trade costs. These regional pairs usually consist of a small exporter and a large importer. Of the 100 bilateral pairs with the most elastic import demand ($\varepsilon_{ij} < -20$), over half of these pairs involve a U.S. state importing from a Canadian province. The most elastic trade flow is Maryland's demand for imports from Saskatchewan, which has an elasticity of -200.9.

The parameter estimates of the translog function and the market shares are also used to calculate the elasticity of substitutions. The elasticities of substitution are calculated using equation (8) for the elasticities between two goods. Own pair, like Alabama-Alabama, are excluded because they will have negative substitution elasticities, indicating tautologically that a good is a complement with itself. Figure 2 reveals the distribution of substitution elasticities, with a mean

[20] It is unclear whether all of the fitted import shares are non-negative in his calculations.

of 2.46 and a median substitution elasticity of 1.56. The lower mean in the translog estimation indicates that the single parameter estimate in the CES model is likely to be over-estimating the elasticity of substitution.

All the product pairs have positive elasticities, confirming the Armington assumption that these goods are substitutes. Over half of the bilateral pairs have substitution elasticities close to one or unitary elasticity of substitution. For these pair of goods, say good A and B, a one percent increase in the relative price of good A increases relative demand of good B by one percent. A majority of these goods do not have large substitution elasticities, which is reasonable since the comparisons are made on regional goods within two countries. Only one percent of pairs have substitution elasticities above 15, with a maximum elasticity of 37. Goods from Alberta and Ohio are one of the most substitutable pair with an elasticity of 37. This might be attributed to similarities in both regions' manufacturing bases, in which metals and petrochemicals are important.

4.3 Border Effects

With these structural parameters, the border between the U.S. and Canada can be removed as a counterfactual simulation to estimate the size of the border effects. Following Anderson and Van Wincoop (2003) and Balistreri and Hillberry (2007), I calculate the border effect by computing the ratio of intranational trade flows and international trade flows with borders, relative to the ratio of trade flows with no borders:

$$\text{Border Effect } = \frac{Intra_{BB}}{Inter_{BB}} / \frac{Intra_{NB}}{Inter_{NB}} \tag{27}$$

where $Intra$ is the nominal international trade flows, and $Inter$ is the nominal international trade flows. The subscript BB refers to the trade equilibrium with borders, and NB refers to the counterfactual equilibrium with no borders. The trade flows used for calculating the border effects are the predicted trade flows in the respective equilibria.

Since the operational GE has been fully calibrated in the estimation stage, the counterfactual analysis is easily done by locking in the structural parameters and setting the border costs (δ) to zero. The model is then solved to obtain the new counterfactual equilibrium. This method of calculating the border effect is preferable as regional incomes can change with the removal of borders (Balistreri and Hillberry, 2007). A last technical detail in the counterfactual analysis is to choose a numeraire so that the aggregation across the trade flows is consistent. For both counterfactual analyses with the CES and translog model, the f.o.b. output from Alabama is chosen as the unit of measure.

Estimates of the border effect are presented in table 4. The border effects for the CES model replicates the results in Balistreri and Hillberry (2007). Border effects for both Canada and the U.S. in the translog model are smaller than in the CES model. Despite the larger estimated tariff equivalent in the translog model, the border effect for the U.S. is reduced by half: the border causes the intranational trade to be only twice the cross-border trade compared to a factor of 4.85. The reduction of the border effect for Canada is larger than the U.S.: the border effect for Canada is three times smaller than in Balistreri and Hillberry (2007). The estimates are also smaller than those in Anderson and Van Wincoop (2003), who estimate border effects of 2.5 for the U.S. and 10.5 for Canada.

The reason for the lower border effects is the smaller change to trade flows when the border is removed. While the decrease in intranational trade flows are similar under both models, the cross-border trade flows increase less in the translog model. The varying elasticities allow each region to respond individually to the border removal. The difference in trade flows is larger for Canada, which accounts for the big difference in Canada's border effect estimates. This suggest that the translog form may assign larger trade costs to explain the smaller change in trade flows.

When the border is removed, trade costs are reduced and each region will experience an increase in welfare levels. Changes in welfare levels are plotted against changes in expenditure on the home good in figures 3 and 4. These are done for the CES and translog model. One key difference between the two models is the welfare gains Canada experiences with the border removal. While the U.S. have similar welfare gains under both models, Canada has an additional 50 percent increase in welfare levels in the translog model.

Welfare gains are also calculated using the ACR formula, and the changes in welfare levels are plotted in figures 3 and 4 using the CES estimate for the own-price elasticity. In the CES model (figure 3), the welfare calculations match the welfare gains from the counterfactual calculations[21]. But this is not the case with the translog model (figure 4). In the translog model, with variable trade elasticities, the linear relationship between welfare gains and changes in home goods expenditure breaks down. Moreover, the ACR formula is not a good measure of welfare responses in the translog model. The average welfare gains in the counterfactual calculations are 67.2 percent for

[21] There is, however, a small discrepancy between the counterfactual calculations and the formula calculations. There is an average of 1.33 percent difference between the two welfare calculations for the Canadian provinces. The difference for the U.S. states is smaller at an average of 0.04 percent.

Canadian provinces and 0.7 percent for U.S. states (measured on the left y-axis), while the average welfare gains in the calculation is 8.1 percent for Canadian provinces and 0.2 percent for U.S. states (measure on the right y-axis). The ACR formula cannot be applied to a translog model, and it is not a useful summary measure of welfare changes when trade liberalizes.

5 Rising International Trade Restrictiveness

The results from the previous section provide assurance that the translog gravity model is suitable to estimate the elasticities and to analyze welfare effects of trade policies. I apply the translog model to the international data covering the OECD and BRICS countries. Two counterfactual scenarios are examined: the welfare implications when a country increases its trade barriers by 50 percent, and the welfare effects of China retreating from the world trading system. In the counterfactual analysis, the f.o.b. output from the U.S. is arbitrarily chosen as the numeraire.

5.1 Data

The estimation covers 39 countries consisting of 34 OECD countries and five BRICS countries in 2006[22]. The BRICS countries of Brazil, Russia, India, China and South Africa are included in the sample to make it a more representative data set. The countries in the data set expands the subset of OECD countries examined in Eaton and Kortum (2002) and Novy (2012). The 39 countries make up about 90 percent of the world's GDP in 2006. Nominal GDP is from the World Bank's World Development Indicators (WDI). Distances are taken from the CEPII gravity data set and are measured as the population weighted average of distance of the largest cities between countries. This measure of distance is useful as it provides internal distances within a country. Distances are normalized by the shortest distance pair (Luxembourg-Luxembourg). The home consumption variable equals one if the importing country is consuming its own exports.

The main variable is the bilateral trade flows that are aggregate nominal trade values reported to the UN COMTRADE system. There are often two values reported for each bilateral trade flow from country A to country B: exports by country A to B and imports by country B from A. One can either take an average of the two values or choose a flow that is more accurate. The import

[22] The 34 OECD countries are Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, South Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Switzerland, Turkey, United Kingdom, and United States. The five BRICS countries are Brazil, Russian Federation, India, China, and South Africa.

flows are chosen because the importing country is assumed to be more conscientious in recording trade values since tariff revenues depend on it. If the receiving country does not record an import flow, the missing values are supplemented with the export flows from the sending country.

The country's own trade with itself is often ignored in gravity model estimation because own flows are not reported in the data. We can, however, calculate these flows using output accounting methods. A country's own trade flow, or its consumption of home goods, is assumed to be the difference between its GDP and the total exports to all countries in the UN COMTRADE database. The home consumption value includes consumption of goods and services. The service component of home consumption is removed using the ratio of service in the GDP, taken from the World Development Indicators. The sample then consists of 1521 trade flows. Since these are aggregate trade flows among large countries, there are no zeroes in the data.

As in the North American data, there is a discrepancy between the GDP and expenditure of a country, measured as the value of total imports. Here, the discrepancy can be attributed to the incomplete set of import partners. Thus, an artificial measure of expenditure is created by aggregating the import values and treating that as the country's expenditure.

5.2 Estimation Results

Estimates for the own-price elasticities and the border taxes are presented in table 5. Conditional on the value of the distance elasticity of trade cost ($\rho = 0.267$), the own-price elasticity from the CES model and the average own-price elasticity from the translog model are similar in magnitude. The CES estimate for the own-price elasticity is $(1 - \sigma) = -4.44$ while the average own-price elasticity from the translog model is $\overline{\varepsilon_{ij}} = -4.68$. The CES elasticity of substitution can be recovered easily from the own-price elasticity estimate. The CES substitution elasticity is $\sigma = 5.44$, which is three times larger than the average substitution elasticity of 1.59 for the translog model.

The two models also differ in their estimates for δ. In the CES model, the estimate for δ is 0.643, which implies that there is a 90 $[= \exp(0.64) - 1]$ percent ad valorem tariff equivalent when the country consumes a foreign good. In the translog model, the estimate for δ is 2.22, which means that there is a 817 $[= \exp(2.22) - 1]$ percent ad valorem tariff equivalent on foreign goods. These estimates are much larger than the estimate obtained with the North American data. It could be that the U.S.-Canada border costs are lower than most border costs. It is more probable that the higher estimate for the border tax is explained by a lack of variation in the home consumption variable. In the international data, each country consumes only one home good while in the North American data, each region consumes at least ten home goods. All estimates of elasticities and border tax are significant at the one percent level.

The translog estimates of α_n and β_{nn} are presented in table 6. The α_n parameters inform us about the importance of a country's goods in the expenditure function. It is then no surprise that the large manufacturing countries have the largest weight: the U.S. (14 percent), Japan (9 percent), China (8 percent), India (5 percent), and Germany (5 percent).

The average own-price elasticity estimated using the translog model closely matches the estimate from the CES model. The distribution of own-price elasticities of imports in figure 5, however, has a higher median of -3.18. There are bilateral pairs with very elastic relationships, which creates a heavy leftward skew in the distribution. These fifteen pairs (or the top one percent) have elasticities smaller than -28, with the most elastic pair being the Spain-U.S. with an elasticity of -167. These pairs have exporters trading with large countries (the U.S., Japan, and United Kingdom), resulting in small market shares and elastic import demands.

It is informative to examine the bilateral elasticities of a large country, say China, to have a better understanding of its relationship with its trading partners. China's own-price elasticities are plotted against its predicted import share in figure 6, and the exporters are identified by their alpha-3 country codes. The own-price elasticities do not have a clear linear relationship with the import shares as the elasticities also depend on the β_{ii} parameters that are exporter-specific.

These elasticities capture the effects of trade costs and exporter size on import demand, through the market shares. Large manufacturing countries, like the U.S. (USA), Canada (CAN) and Germany (DEU), can achieve economies of scale and sell their goods at a lower f.o.b. price compared to smaller countries. They would then have a relatively inelastic import demand. The cost of trading with China also plays a part. Goods from regional countries like Japan (JPN), Korea (KOR), India (IND), and Australia (AUS) incur less trade costs and can be sold at a lower price in China. Thus, large and neighboring countries can capture bigger market shares, and face relatively inelastic demand.

Substitution elasticities are calculated for all country pairs with positive predicted import shares using $\hat{\beta}_{ij}$ and $\hat{s}_{ij}$. The distribution of the Allen elasticity is presented in figure 7. The mean and median substitution elasticities are 1.59 and 1.39 respectively. The positive elasticities indicate that both goods in each bilateral pair are substitutes, a result that is consistent with the Armington assumption. There is a long right tail in the distribution with only four bilateral pairs with an elasticity above 10. Over 90 percent of the bilateral pairs have elasticities below

2, implying that most pairs, despite being substitutes as assumed in Armington model, are not strong substitutes.

5.3 Counterfactual Analysis 1: Rising Protectionism

The first counterfactual analysis imagines a scenario where each country becomes more protectionistic. The higher trade barriers are represented in the model by increasing the cost of trading with country j by 50 percent, i.e $\tau_{ij}^{'} = \tau_{ij} \times 1.5 \ \forall i \neq j$. The welfare effects of protectionism are examined for each country while the other countries remain at status quo. In the endowment economy, the changes in trade costs will not affect the nominal income of the country. Instead, changes in trade costs will affect the real income through changes to the price of domestic goods, thereby affecting the cost-of-living index. The welfare effects are compared to those using the ACR formula.

The 50 percent increase in the trade costs is performed for each country separately, and the changes to welfare, prices and cost of living are presented in table 7. A rise in protectionism has a varied impact on the welfare of countries. Welfare losses range from a small -4.8 percent decrease for the U.S. to a large -32.8 percent decrease for Iceland. The variation in the welfare changes can be explained by the expenditure on the home goods, which recalls the welfare results in Arkolakis et al. (2012). The home good expenditure is affected by the size of the country and its weight in the expenditure function.

First, country size is negatively related to the welfare loss due to higher trade barriers. Small countries like Estonia, Iceland, Luxembourg, Slovak Republic, and Slovenia suffer the highest welfare losses, while large countries like China, Germany, Japan, the United Kingdom, and the U.S. suffer the lowest welfare losses. This is because country size is indicative of whether the country has to continue importing even after increasing its barriers. When imports become more expensive, consumers substitute to their home goods. But small countries are less likely to have suitable substitutes to the imports, and are more likely to continue to consume imports. The expensive imports will push up the cost-of-living index and decrease the welfare levels of the country.

Second, welfare losses are mitigated by the importance of a country's good in the expenditure function, which is determined by the α_n parameter. From table 6, the U.S. has the largest weight, followed by Japan, then China. A large weight means that the good will have a large demand compared to the other goods. When the importing country puts up its trade barriers, local consumers will increase their demand for the home good, which pushes up prices. If the country has a large weight, other countries will continue demanding this good despite the higher price, further driving up the prices. The increases in the domestic prices will increase real income, and this will dampen the welfare losses from raising the trade barriers. The U.S., with the largest weights, experiences the largest increase of 10.5 percent in real income and the smallest welfare losses of 4.75 percent.

The changes in welfare levels and expenditure on home good for each country are not linearly related. The welfare levels are plotted in figure 8 and represented by their alpha-3 country codes. As a comparison, the welfare changes are also calculated according to the ACR formula using the CES estimate of the own-price elasticity. They are represented by the line in figure 8. Since the ACR formula summarizes the welfare changes in Novy (2012), these welfare calculations can also be thought of as counterfactual calculations in that model.

The counterfactual welfare calculations are heterogeneous and do not exhibit any linear relationship with changes to home good expenditure. These welfare calculations contrast sharply with the welfare changes calculated with the ACR formula, which exhibit little variation and underestimate the welfare loss of raising trade barriers. As the formula implies, welfare has a negative relationship with changes in home good expenditure. But the formula imposes a strict linear relationship between welfare changes and changes in home good expenditure. Since home good expenditure increased between 10 to 14 percent, the variation in welfare calculations from the formula is small: average welfare loss is 2.6 percent with a minimum loss of 2.1 percent and a maximum loss of 3.0 percent. In contrast, the average counterfactual welfare losses is 27 percent with a minimum loss of 4.75 and a maximum loss of 33 percent. The welfare calculations from the ACR formula also underestimates the welfare losses. Most significantly, the welfare losses are underestimated by eight times for China, France, India, and the U.K., and underestimated by more than ten times for Australia, Brazil, Canada and Russia.

The large difference in welfare losses is because of the varied trade responses through the bilateral substitution elasticities in the translog model[23]. In the CES model, an increase in the price of a good causes the consumer to substitute away from that good and spread the extra income evenly across all other goods. In the translog model, the varying substitution elasticities mean that the consumer will not spread the extra income evenly. Without the constant elasticity of substitution, welfare cannot be summarized into one sufficient statistic.

[23]This result is supported by Ossa (2012) who finds that the welfare effects in trade models are amplified if industry dimensions of trade flows are taken into account. He finds that certain imports are more important to an economy and losing access to them will mean a larger welfare loss. This is analogous to the translog model where certain trade flows are more important to a country and when trade barriers are increased, the welfare losses will be higher.

5.4 Counterfactual Analysis 2: China Behind a Great Wall

For the second counterfactual analysis, a scenario is proposed where China is removed from the world trade system. China's participation in the world market has reshaped international trade and more importantly, has raised the income and welfare of its citizens. The effects of China's participation were amplified by China's accession into the World Trade Organization (WTO). It will be revealing to examine the effect of China's removal from world markets on each country's welfare levels and trade flows. China's autarkic state is achieved by increasing the bilateral distance of China and the world by 100 times (i.e. $dist'_{i,China} = dist_{i,China} \times 100 \;\; \forall i \neq China$ and $dist'_{China,j} = dist_{China,j} \times 100 \;\; \forall j \neq China$)[24]. Any trade with China will occur at a high cost. The changes to welfare levels and China's imports are summarized in table 8.

Welfare levels falls for all countries when a major manufacturing country like China retreats from the world trading system. As expected China suffers the most when it stops trading; its welfare level drops by 61 percent. Clearly it is not in China's interest to retreat from the world. All the other countries in the system suffer a welfare loss of around 0.5 percent, with China's regional trade partners (Australia, Japan, Korea, India and New Zealand) experiencing a larger drop in their welfare levels of around 1-2 percent. These welfare losses are small and it indicate that even though countries might suffer welfare loss from not trading with China, the consequences are not catastrophic.

When China stops trading with the world, it has to rely on itself to supply all its goods. Chinese consumers will decrease their demand for expensive imports. China's consumption of its own goods increases by 69 percent, which puts an upward pressure on domestic prices and increases the cost of living. The higher cost of living is a major reason why China experiences such a large welfare loss.

With the higher trade barriers in and out of China, all countries decrease their exports to China and their trade responses are reflected in their respective own-price elasticity, as shown in figure 6. Iceland, Ireland, Portugal, Spain, and United Kingdom, at the bottom left corner of figure 6, have the most elastic trade flows with China. These countries also experience the largest decrease in their exports to China, a decrease of more than 300 percent. Conversely, countries at the right of figure 6 like Australia, Korea, Japan and New Zealand have relatively inelastic import demands and the decrease in China's imports from these countries is smaller. As China is not

[24] The usual approach of setting the bilateral distance with China to infinity is not taken because this causes infeasibility in the model.

fully in autarky, China still trade with other countries, which suggests that the goods from these countries are not as substitutable as the other goods.

The welfare losses are also calculated with the ACR formula using the CES estimate of the own-price elasticity. Aside from china, the welfare losses from the counterfactual analysis and the welfare formula are plotted in figure 9. The welfare calculations from the counterfactual analysis are more heterogeneous than those from the ACR formula. They also do not display a clear linear relationship with changes in the expenditure on home goods. Even though the welfare losses are small, the welfare calculations underestimate the welfare losses, which may trivialize the withdrawal of China from the trading system.

6 Conclusion

The gravity model has been instrumental in helping us measure the size of the gains from trade. But the theoretical models that motivate the gravity model are single parameter models that might not be realistic in capturing trade responses. This paper adopts a different approach by augmenting a standard gravity model with the more flexible translog expenditure function. It breaks the link between the own-price and cross-price elasticities, while also giving us a unique elasticity for each bilateral pair. I apply the translog gravity model to two data sets covering inter-regional trade within North America, and international trade among OECD and BRICS countries. In both data sets, the average own-price elasticity is similar to the estimate in the CES model, but the average substitution elasticity is lower than the CES estimate.

I estimate the model using an MPEC approach that imposes theory consistent general equilibrium restrictions on the estimation. The model, once calibrated via structural estimation, is used in three counterfactual analyses. First, the borders between Canada and the U.S. are removed. The border effects estimated under the translog gravity model are lower than those under the CES model. The difference is more pronounced for Canada. The border effects are lower because the increase in cross-border trade flows are not as large as under the CES model. Second, trade barriers for each country are raised. Every country experiences a welfare loss when it raises its trade barriers but the welfare loss ranges from four to 30 percent. Countries with large manufacturing bases and weights in the expenditure function suffer smaller welfare losses. Third, China is removed from the trading system and it suffers the largest welfare loss. Even though China is an important player in the system, its removal from the trading system decreases the welfare of most countries by only one percent.

In these counterfactual simulations, the welfare changes do not have a linear relationship with changes in a country's openness as implied by the ACR formula. The welfare changes are also more heterogeneous than those implied by the formula. The ACR formula only applies to a class of models that summarize trade responses via a single parameter. Once we allow varying elasticities across importers, which are more representative of the data, the formula is no longer an accurate measure of welfare; it underestimates the welfare effects of trade policy changes.

This paper complements the work by Melitz and Ottaviano (2008), Feenstra and Weinstein (2010), and Novy (2012) in the search for an alternative to the CES preferences. Once we move away from a single parameter model, we can produce richer results that are a closer match to the stylized facts. This paper adopted a more flexible demand system with a simple Armington assumption on the supply side. But this flexible approach can probably be extended to include richer supply-side details in the trade model, which can produce more interesting results.

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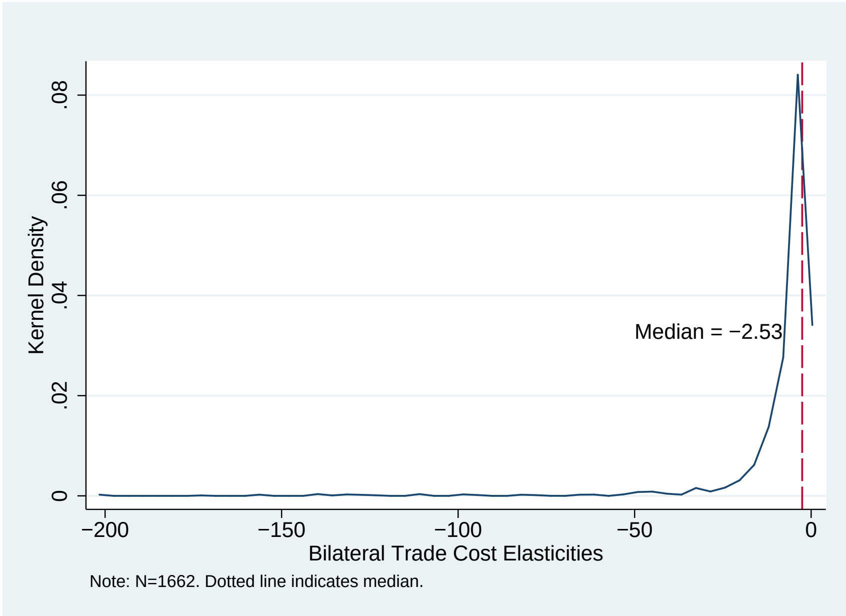
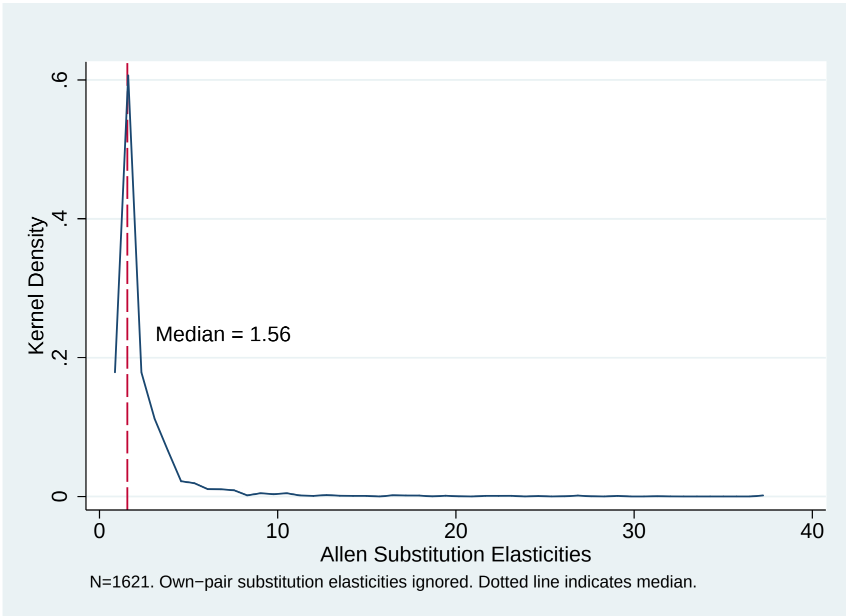
Figure 1: Distribution of Bilateral Own-Price Elasticities — North America



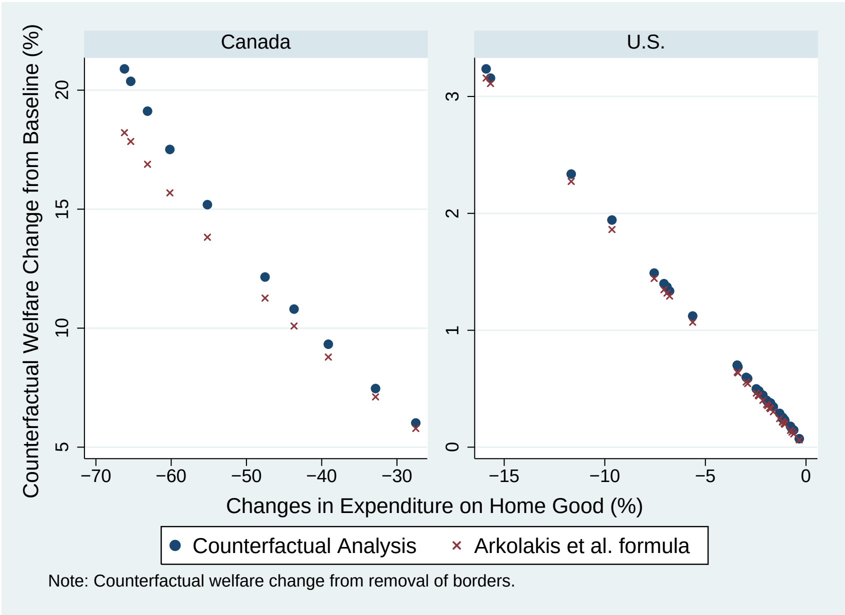
The bilateral own-price elasticities of imports are calculated using equation 10 for the Canadian and U.S. regions. While the average elasticity is -6.39, the median -2.53. The long left tail contains pairs that have very elastic relationship. These pairs usually consist of a small exporter and a large importer. The data are inter-regional trade flows between Canada and the U.S. from Anderson and Van Wincoop (2003).

Figure 2: Distribution of Substitution Elasticities — North America



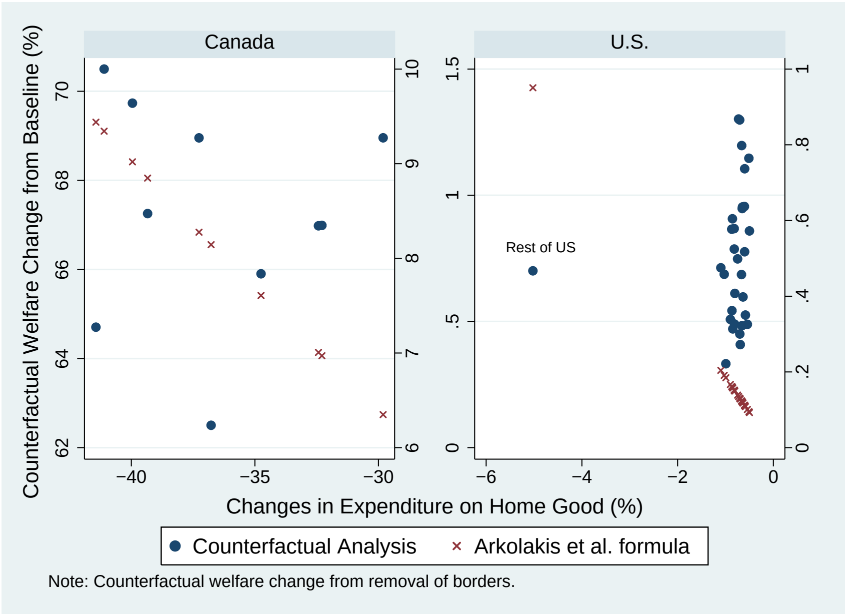
The substitution elasticities are calculated using the Allen elasticity of substitution for the Canadian and U.S. regions. The mean elasticity is 2.46 and the median is 1.56, which is much less than the CES estimate of 5. This suggests that the CES estimates is over-estimating the elasticity of substitution.

Figure 3: Welfare Change from Border Removal (CES)



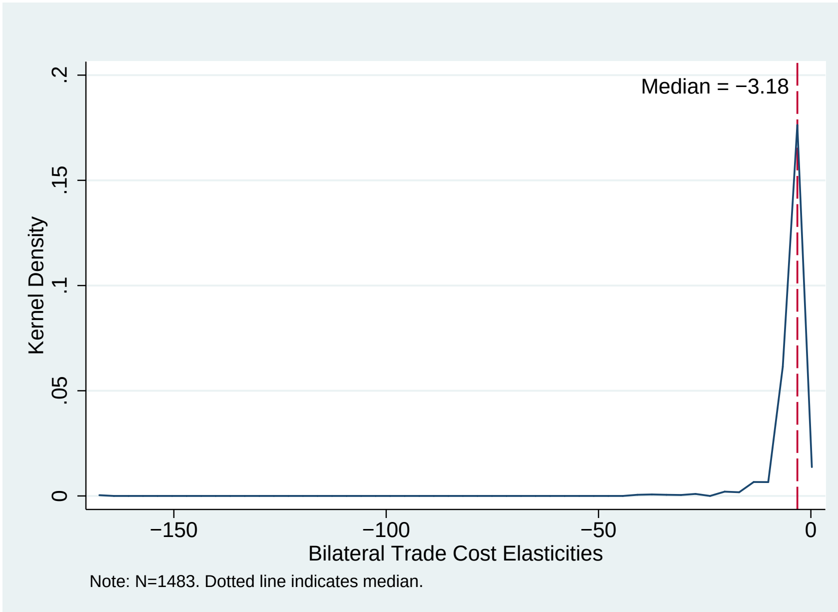
Welfare changes for the Canadian and U.S. regions when the border is removed are plotted against the expenditure on home good. The counterfactual calculations are done with the CES model. These are compared to the welfare changes according to the formula in Arkolakis et al. (2012). Both show a linear relationship with expenditure on the home good. There is a slight discrepancy between the welfare changes from the counterfactual analysis and formula calculation.

Figure 4: Welfare Change from Border Removal (Translog)



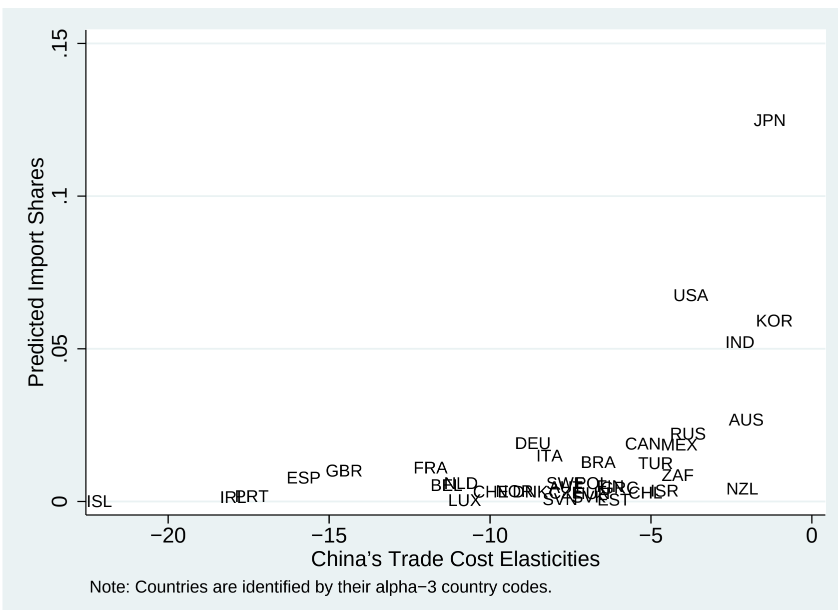
The counterfactual calculations are done with the translog model. The linear relationship between the welfare changes and the expenditure on the home good is only present in the welfare calculations using the ACR formula. The outlier in the right panel is the Rest-of-U.S. region. The left vertical axis of each panel measures the welfare changes from the counterfactual calculations. The right vertical axis measures the welfare changes from the formula calculations.

Figure 5: Distribution of Bilateral Own-Price Elasticities — International



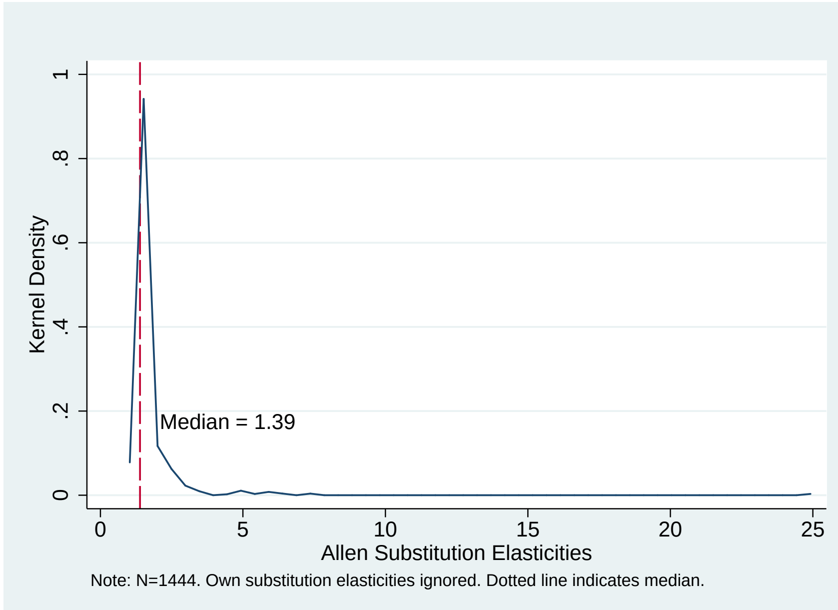
The bilateral own-price elasticities of imports are calculated for the OECD and BRICS countries. The mean is -4.680 and the median is -3.18. There are 15 pairs (top one percent) that have elasticities below -28, which explains the long left tail. The data used is aggregate trade flows from the UN COMTRADE.

Figure 6: Bilateral Own-Price Elasticities for China



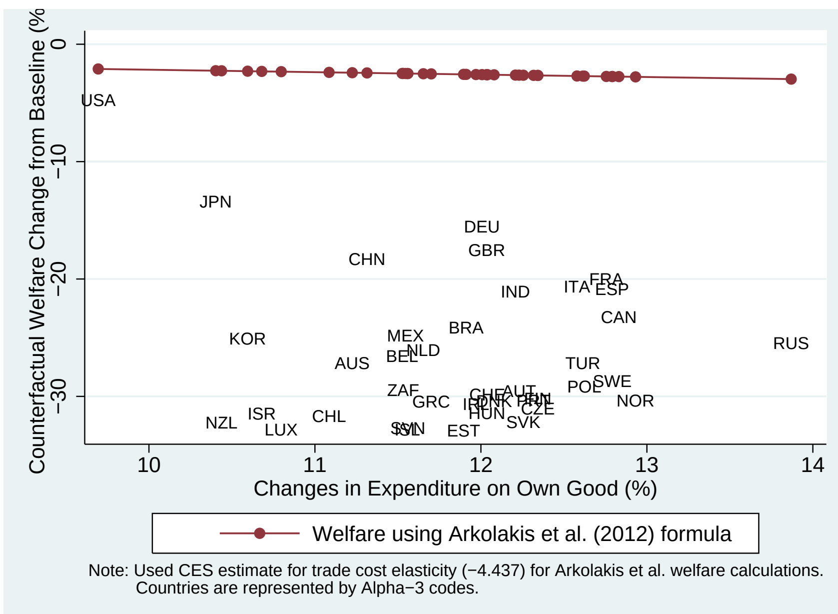
The bilateral own-price elasticities of China's imports are plotted against the predicted import shares in China. Exporters with larger market shares in China will have more inelastic relationship. These countries tend to be large or neighboring countries, like Australia (AUS), Japan (JPN), Korea (KOR), and the United States (USA).

Figure 7: Distribution of Allen Substitution Elasticities — International



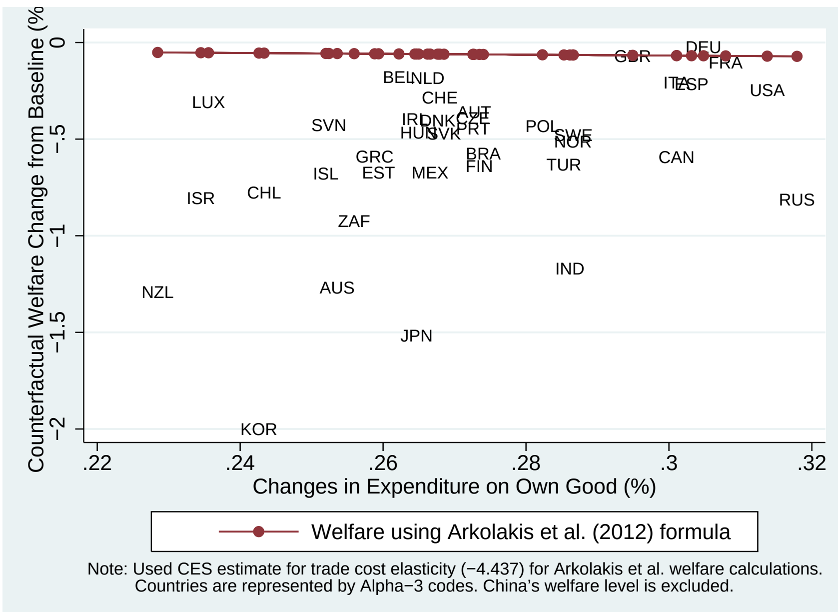
The substitution elasticities are calculated using the Allen elasticity of substitution for the OECD and BRICS countries. The mean is 1.59 and the median is 1.39, which are much lower than the CES estimate of 5.44. The long right tail is explained by four bilateral pairs with elasticities above 10.

Figure 8: Welfare Changes from Increasing Trade Barriers



Welfare changes are calculated when each country increases its trade barriers while the other countries remain at status quo. The higher trade barriers are achieved by increasing trade costs by 50 percent for each country. Welfare changes are also calculated using the ACR formula and included in the figure. These welfare changes are plotted against the changes in expenditure on home good.

Figure 9: Welfare Changes when China stops Trading



Welfare changes are calculated for all countries, except China, when China stops trading with the world. This is achieved by increasing the cost of importing from and exporting to China by 100 times. Welfare changes are also calculated using the ACR formula and included in the figure. The welfare changes are plotted against the changes in expenditure on home good.

Table 1: Estimates of Distance Elasticities for U.S. and Canada

	(1)	(2)	(3)
$\ln dist_{ij}$	-1.13	-1.25	-1.49
	(0.06)	(0.03)	(0.16)
$home_{ij}$	2.21	1.59	1.55
	(0.11)	(0.06)	(0.06)
Constant	12.08	12.63	14.43
	(0.44)	(0.29)	(1.13)
Fixed Effects?	No	Yes	Yes
Distance Interaction Terms?	No	No	Yes
F-test: Joint significance of interaction terms*			0.00
R^2	0.404	0.895	0.911
N	1612	1612	1612

Note: Dependent variable is $\ln x_{ij}$, the log of bilateral shipment between U.S. states and Canadian provinces. Distance interaction terms are bilateral distance interacted with importer dummy variables. Standard errors are in parentheses. All coefficients are significant at the one percent level.

* P-value for joint test of significance of distance interaction terms.

Table 2: Regression Estimates for U.S.-Canada Data

	(1) CES: $\ln s_{ij}$	(2) Translog: s_{ij}
Own-price Elasticity	$(1-\hat{\sigma}) = -4.00$	$\overline{\frac{\hat{\beta}_{nn}}{\hat{s}_{nj}}} = -6.39$
	(0.05)	
Substitution Elasticity	$\hat{\sigma} = 5$	$\overline{\sigma}_{ij} = 2.46$
	(0.05)	
Border Tax Equivalent (δ)	0.462	0.546
	(0.02)	(0.16)
N	1511	1681

Note: $\overline{\frac{\hat{\beta}_{nn}}{\hat{s}_{nj}}}$ and $\overline{\sigma}_{ij}$ are the average of the bilateral own-price elasticities of imports and substitution elasticities in the translog estimation. Bootstrapped standard errors are in parentheses. All coefficients are significant at the one percent level.

Table 3: Parameter Estimates for U.S. and Canadian Regions (Translog Model)

U.S. State	$\hat{\alpha}_n$	$\hat{\beta}_{nn}$	U.S. State	$\hat{\alpha}_n$	$\hat{\beta}_{nn}$	U.S. State	$\hat{\alpha}_n$	$\hat{\beta}_{nn}$	Canadian Province	$\hat{\alpha}_n$	$\hat{\beta}_{nn}$
Alabama	0.010	-0.022	Massachusetts	0.014	-0.054	North Carolina	0.021	-0.040	Alberta	0.041	-0.050
	(0.0008)	(0.008)		(0.0009)	(0.015)		(0.001)	(0.016)		(0.003)	(0.010)
Arizona	0.014	-0.040	Maine	0.003	-0.010	North Dakota	0.002	-0.012	British Columbia	0.029	-0.029
	(0.001)	(0.009)		(0.0002)	(0.002)		(0.000)	(0.002)		(0.003)	(0.006)
California	0.104	-0.178	Maryland	0.011	-0.019	Ohio	0.029	-0.069	Manitoba	0.010	-0.015
	(0.003)	(0.029)		(0.001)	(0.009)		(0.002)	(0.017)		(0.0008)	(0.002)
Georgia	0.018	-0.083	Michigan	0.034	-0.079	Pennsylvania	0.026	-0.056	New Brunswick	0.006	-0.007
	(0.001)	(0.010)		(0.005)	(0.032)		(0.002)	(0.014)		(0.0006)	(0.001)
Florida	0.033	-0.053	Minnesota	0.006	-0.109	Tennessee	0.014	-0.039	Newfoundland	0.006	-0.007
	(0.002)	(0.031)		(0.003)	(0.030)		(0.002)	(0.010)		(0.000)	(0.001)
Idaho	0.004	-0.010	Missouri	0.017	-0.016	Texas	0.065	-0.217	Nova Scotia	0.007	-0.008
	(0.000)	(0.001)		(0.002)	(0.011)		(0.003)	(0.042)		(0.0005)	(0.001)
Illinois	0.025	-0.108	Montana	0.003	-0.010	Vermont	0.002	-0.007	Ontario	0.069	-0.092
	(0.005)	(0.021)		(0.000)	(0.001)		(0.000)	(0.001)		(0.004)	(0.028)
Indiana	0.013	-0.044	New Hampshire	0.002	-0.008	Virginia	0.016	-0.027	Prince Edward Island	0.001	-0.001
	(0.002)	(0.010)		(0.000)	(0.001)		(0.001)	(0.013)		(0.000)	(0.000)
Kentucky	0.011	-0.016	New Jersey	0.023	-0.054	Washington	0.031	-0.070	Quebec	0.047	-0.061
	(0.001)	(0.007)		(0.002)	(0.013)		(0.003)	(0.019)		(0.006)	(0.012)
Louisiana	0.014	-0.030	New York	0.041	-0.046	Wisconsin	0.010	-0.060	Saskatchewan	0.010	-0.014
	(0.001)	(0.011)		(0.002)	(0.019)		(0.002)	(0.016)		(0.0009)	(0.002)
						Rest of US	0.163	-0.605			
							(0.026)	(0.223)			

Note: Bootstrapped standard errors are in parentheses. All coefficients, with the exception of the β_{nn} for Florida and Missouri, are significant at the five percent level.

Table 4: Border Effects for U.S.-Canada Data

	Border Effects		Percentage Change in Trade Flows (%)			
	Canada	U.S.	Canada		U.S.	
			From Canada	From U.S.	From Canada	From U.S.
(1) CES	7.67	4.85	-38.57	371.31	371.31	-2.81
	(0.68)	(0.36)	(1.13)	(35.12)	(35.12)	(0.10)
(2) Translog	2.56	2.06	-43.34	44.84	99.57	-3.16
	(0.10)	(0.37)	(1.95)	(5.73)	(35.85)	(0.35)

Note: Percentage change in trade flows are calculated as $\frac{x^{'}}{x} - 1$ where $x^{'}$ is the trade flow when the borders are removed. Bootstrapped standard errors are in parentheses. All parameters are significant at the one percent level.

Table 5: Estimates for OECD and BRICS Data

	(1) CES: $\ln s_{ij}$	(2) Translog: s_{ij}
Own-price elasticity	$(1 - \hat{\sigma}) = -4.44$	$\overline{\frac{\hat{\beta}_{nn}}{\hat{s}_{nj}}} = -4.68$
	(0.13)	
Substitution Elasticity	$\hat{\sigma} = 5.44$	$\overline{\sigma_{ij}} = 1.589$
	(0.13)	
Border Tax (δ)	0.64	2.22
	(0.04)	(0.74)
N	1521	1521

Note: $\overline{\frac{\hat{\beta}_{nn}}{\hat{s}_{nj}}}$ and $\overline{\sigma_{ij}}$ are the average of the bilateral own-price elasticities of imports and substitution elasticities in the translog estimation. Bootstrapped standard errors are in parentheses. The coefficients are significant at the one percent level.

Table 6: Parameter Estimates for OECD and BRICS countries

Country	Code	$\hat{\alpha}_n$	$\hat{\beta}_{nn}$	Country	Code	$\hat{\alpha}_n$	$\hat{\beta}_{nn}$	Country	Code	$\hat{\alpha}_n$	$\hat{\beta}_{nn}$
Australia	AUS	0.037	-0.055	Greece	GRC	0.009	-0.027	Norway	NOR	0.008	-0.031
		(0.003)	(0.007)			(0.001)	(0.005)			(0.001)	(0.006)
Austria	AUT	0.011	-0.037	Hungary	HUN	0.006	-0.019	Poland	POL	0.012	-0.042
		(0.001)	(0.005)			(0.001)	(0.003)			(0.001)	(0.006)
Belgium	BEL	0.017	-0.061	Iceland	ISL	0.001	-0.005	Portugal	PRT	0.009	-0.030
		(0.002)	(0.009)			(0.000)	(0.001)			(0.001)	(0.006)
Brazil	BRA	0.046	-0.086	India	IND	0.052	-0.117	Russia	RUS	0.028	-0.085
		(0.004)	(0.013)			(0.002)	(0.012)			(0.002)	(0.018)
Canada	CAN	0.044	-0.010	Ireland	IRL	0.006	-0.026	Slovak Rep	SVK	0.003	-0.011
		(0.002)	(0.017)			(0.001)	(0.005)			(0.000)	(0.002)
Chile	CHL	0.009	-0.015	Israel	ISR	0.006	-0.016	Slovenia	SVN	0.002	-0.006
		(0.001)	(0.003)			(0.001)	(0.003)			(0.000)	(0.001)
China	CHN	0.079	-0.132	Italy	ITA	0.039	-0.123	South Africa	ZAF	0.019	-0.036
		(0.003)	(0.022)			(0.001)	(0.021)			(0.003)	(0.008)
Czech Rep	CZE	0.007	-0.023	Japan	JPN	0.089	-0.163	Spain	ESP	0.036	-0.124
		(0.001)	(0.003)			(0.005)	(0.022)			(0.001)	(0.024)
Denmark	DNK	0.008	-0.028	Korea	KOR	0.035	-0.069	Sweden	SWE	0.013	-0.047
		(0.001)	(0.004)			(0.001)	(0.008)			(0.001)	(0.008)
Estonia	EST	0.001	-0.004	Luxembourg	LUX	0.001	-0.004	Switzerland	CHE	0.009	-0.033
		(0.000)	(0.001)			(0.000)	(0.001)			(0.001)	(0.006)
Finland	FIN	0.009	-0.031	Mexico	MEX	0.041	-0.077	Turkey	TUR	0.021	-0.061
		(0.001)	(0.006)			(0.002)	(0.011)			(0.002)	(0.010)
France	FRA	0.038	-0.131	Netherlands	NLD	0.018	-0.067	United Kingdom	GBR	0.039	-0.147
		(0.001)	(0.023)			(0.002)	(0.009)			(0.002)	(0.031)
Germany	DEU	0.049	-0.166	New Zealand	NZL	0.007	-0.009	United States	USA	0.141	-0.254
		(0.003)	(0.034)			(0.001)	(0.001)			(0.018)	(0.055)

Note: Bootstrapped standard errors are in parentheses. All coefficients are significant at the five percent level. Codes are alpha-3 country codes.

Table 7: Changes to Welfare, Income and Cost of Living: Rising Protectionism

Country	Percentage Change from Baseline: Welfare	Cost of Living	Real Income	Country	Percentage Change from Baseline: Welfare	Cost of Living	Real Income	Country	Percentage Change from Baseline: Welfare	Cost of Living	Real Income
Australia	-27.17	38.20	0.66	Greece	-30.44	44.12	0.25	Norway	-30.33	43.91	0.26
	(0.012)	(0.023)	(0.003		(0.005)	(0.011)	(0.001)		(0.006)	(0.013)	(0.001)
Austria	-29.55	42.55	0.43	Hungary	-31.40	46.07	0.20	Poland	-29.15	41.79	0.46
	(0.007)	(0.013)	(0.002)		(0.004)	(0.007)	(0.002)		(0.007)	(0.015)	(0.002)
Belgium	-26.55	37.29	0.83	Iceland	-32.83	48.91	0.02	Portugal	-30.33	43.87	0.23
	(0.010)	(0.019)	(0.008)		(0.001)	(0.002)	(0.000)		(0.006)	(0.011)	(0.000)
Brazil	-24.12	32.93	0.86	India	-21.07	28.06	1.08	Russia	-25.46	35.13	0.73
	(0.020)	(0.035)	(0.000)		(0.020)	(0.032)	(0.000)		(0.016)	(0.028)	(0.004)
Canada	-23.26	32.15	1.41	Ireland	-30.66	44.53	0.22	Slovak Rep	-32.19	47.65	0.12
	(0.026)	(0.047)	(0.007)		(0.005)	(0.009)	(0.001)		(0.002)	(0.005)	(0.001)
Chile	-31.68	46.58	0.14	Israel	-31.47	46.11	0.13	Slovenia	-32.71	48.70	0.06
	(0.004)	(0.009)	(0.001)		(0.004)	(0.008)	(0.000)		(0.001)	(0.003)	(0.001)
China	-18.30	25.79	2.77	Italy	-20.64	28.27	1.79	South Africa	-29.47	42.14	0.24
	(0.025)	(0.039)	(0.000)		(0.017)	(0.028)	(0.009)		(0.011)	(0.023)	(0.001)
Czech Rep	-31.03	45.37	0.26	Japan	-13.41	19.49	3.47	Spain	-20.87	28.15	1.40
	(0.004)	(0.009)	(0.003)		(0.020)	(0.028)	(0.000)		(0.016)	(0.026)	(0.007)
Denmark	-30.39	44.08	0.30	Korea	-25.08	34.77	0.97	Sweden	-28.70	40.89	0.45
	(0.005)	(0.011)	(0.002)		(0.015)	(0.027)	(0.005)		(0.009)	(0.017)	(0.000)
Estonia	-32.92	49.12	0.03	Luxembourg	-32.82	48.94	0.05	Switzerland	-29.83	43.08	0.40
	(0.001)	(0.002)	(0.000)		(0.001)	(0.002)	(0.000)		(0.008)	(0.016)	(0.002)
Finland	-30.19	43.61	0.25	Mexico	-24.81	34.55	1.17	Turkey	-27.16	38.10	0.59
	(0.006)	(0.013)	(0.003)		(0.018)	(0.032)	(0.006)		(0.011)	(0.021)	(0.003)
France	-20.01	27.51	2.00	Netherlands	-26.03	36.42	0.91	United Kingdom	-17.52	24.02	2.29
	(0.019)	(0.031)	(0.050)		(0.011)	(0.020)	(0.005)		(0.019)	(0.029)	(0.012)
Germany	-15.52	22.30	3.32	New Zealand	-32.23	47.71	0.11	United States	-4.75	15.98	
	(0.010)	(0.015)	(0.100)		(0.002)	(0.005)	(0.001)		(0.010)	(0.011)	

Note: Percentage changes are calculated as $\frac{x'}{x} - 1$ where x' is the outcome when trade cost, $\tau_{ij} \forall i \neq j$, increases by 150%, and x is the baseline and this is done for each country. Cost of living is measured as the price of one unit of welfare. U.S. f.o.b. output is the numeraire so the change to its output is zero. Bootstrapped standard errors are in parentheses. All counterfactual results are significant at the one percent level, except the real income changes for Germany.

Table 8: Changes to Welfare and Imports: China Behind a Great Wall

	Percentage Change from Baseline			Percentage Change from Baseline			Percentage Change from Baseline	
Country	Welfare	China's Imports	Country	Welfare	China's Imports	Country	Welfare	China's Imports
China	-60.79	68.62	Greece	-0.59	-73.51	Norway	-0.51	-113.93
	(0.082)	(0.147)		(0.0006)	(0.177)		(0.0007)	(0.365)
Australia	-1.27	-25.37	Hungary	-0.47	-83.92	Poland	-0.43	-84.58
	(0.0008)	(0.072)		(0.0007)	(0.220)		(0.0007)	(0.223)
Austria	-0.36	-94.50	Iceland	-0.68	-270.22	Portugal	-0.45	-214.47
	(0.001)	(0.265)		(0.001)	(1.379)		(0.0007)	(0.928)
Belgium	-0.18	-141.68	India	-1.17	-28.56	Russia	-0.81	-48.53
	(0.001)	(0.529)		(0.0008)	(0.064)		(0.0008)	(0.102)
Brazil	-0.57	-83.73	Ireland	-0.40	-221.28	Slovak Rep	-0.47	-84.78
	(0.001)	(0.699)		(0.0008)	(1.004)		(0.0007)	(0.225)
Canada	-0.59	-66.58	Israel	-0.81	-56.10	Slovenia	-0.43	-95.51
	(0.001)	(0.405)		(0.0005)	(0.123)		(0.0008)	(0.275)
Chile	-0.78	-63.35	Italy	-0.21	-104.49	South Africa	-0.93	-51.46
	(0.0007)	(0.370)		(0.001)	(0.305)		(0.0007)	(0.218)
Czech Rep	-0.39	-93.87	Japan	-1.52	-17.04	Spain	-0.22	-202.42
	(0.0008)	(0.270)		(0.002)	(0.041)		(0.001)	(0.809)
Denmark	-0.40	-107.69	Korea	-2.00	-14.55	Sweden	-0.48	-94.91
	(0.0008)	(0.333)		(0.002)	(0.033)		(0.0007)	(0.272)
Estonia	-0.67	-75.04	Luxembourg	-0.31	-131.63	Switzerland	-0.29	-123.04
	(0.0005)	(0.183)		(0.0009)	(0.468)		(0.0009)	(0.457)
Finland	-0.64	-77.19	Mexico	-0.67	-51.75	Turkey	-0.63	-60.60
	(0.0006)	(0.192)		(0.001)	(0.260)		(0.0007)	(0.133)
France	-0.10	-152.36	Netherlands	-0.18	-136.35	United Kingdom	-0.07	-188.32
	(0.001)	(0.569)		(0.001)	(0.485)		(0.001)	(0.888)
Germany	-0.02	-113.31	New Zealand	-1.29	-26.41	United States	-0.25	-51.39
	(0.001)	(0.406)		(0.0007)	(0.077)		(0.002)	(0.283)

Note: Percentage changes are calculated as $\frac{x'}{x} - 1$ where x' is the outcome when distance between China and its trading partners, $dist_{i,China}$ and $dist_{China,j}$ where $i, j \neq China$, increases by 10000%, and x is the baseline. U.S. f.o.b. output is the numeraire so the change to its output is zero. Bootstrapped standard errors are in parentheses. All counterfactual results are significant at the one percent level, except the welfare changes for France, Germany, Italy, Netherlands, the U.K. and the U.S.