Structural Estimation of a Flexible Translog Gravity Model

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Abstract

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 structurally estimate the parameters and conduct counterfactual analyses. Welfare responses are larger and more heterogeneous than those implied by the formula in Arkolakis et al.

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

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A central question in international economics is how best to measure the gains from trade. A workhorse empirical tool to measure welfare gains in international trade is the empirical gravity model of trade. A wide variety of theoretical models provide microeconomic foundations for the gravity model and interpret the bilateral trade pattern[1]. Despite many different motivations for trade, recent work by Arkolakis, Costinot and Rodriguez-Clare (2012) has shown that a broad class of quantitative trade models have equivalent macro-level 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. A single parameter simplifies theoretical derivations and provides applied researchers with a parsimonious framework for estimating trade responses. But trade responses to geographic frictions can vary across importers and exporters, 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 differ from other quantitative trade models.

The flexible approach augments a standard gravity model with a more

[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.

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 (2013) 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. Arkolakis et al. (2010) show that the translog form, with the parsimony achieved under the same estimating restrictions Novy imposes and an assumption of a Pareto distribution of firm productivity, implies the same welfare implications as other gravity models.

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, and these zeroes can be directly included in the estimation[4].

The estimation technique involves the solution of a mathematical program with equilibrium constraints (MPEC) as proposed by Judd and Su (2012).

[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.

This structural estimation approach has the benefit of ensuring full theoretic consistency[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 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 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). Their formula, henceforth called the ACR formula, establishes a linear relationship between a country's expenditure on its home goods and the own-price elasticity of imports. When elasticities are allowed to vary in the translog model, this relationship no longer holds. 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.

Compared to the calculations using the ACR formula, the counterfactual

[5]It also allows a straightforward and transparent link between the estimating model and the counterfactual model. See Balistreri and Hillberry (2008) for a discussion of this issue in the context of the Anderson and Van Wincoop (2003) gravity model.

welfare calculations have a higher average welfare losses and are more heterogeneous than implied by the formula. When trade barriers are increased by 50 percent for each country at a time, the average welfare loss across the countries is 26 percent according to the counterfactual calculations, and 2.6 percent according to the formula calculations. The range of welfare losses is 4.7 to 32.9 percent in the counterfactual calculations, and only 2.1 to 3.0 percent in the formula calculations. When China retreats from the world market, the average welfare loss for the rest of the world is 0.6 percent according to the counterfactual calculations, and 0.06 percent according to the formula calculations. The range of welfare losses is 0.02 to 1.52 percent in the counterfactual calculations, and only 0.05 to 0.07 in the formula calculations.

The key distinction of the translog model is that trade responses are not summarized by a single elasticity parameter: trade responses can vary bilaterally. Despite different motivations for trade in many trade models, a single structural parameter is often used to govern the responsiveness of trade to changes in trade costs for a parsimonious framework in estimation[6]. But it is unrealistic to assume that every country has the same trade responses, regardless of country size and distance to market. Changes in trade costs will affect relative prices, causing consumers to substitute between goods. A single elasticity implies that changes to the demands for these goods will be the same.

The remainder of the paper is organized as follows. Section 2 provides a motivation for relaxing the assumption of a single trade response in the gravity model. The flexible approach is developed in Section 3, and compared to Novy

[6]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).

Table 1: Estimates of Distance Elasticities

Dependent variable: $\ln x_{ij}$	(1)	(2)	(3)	(4)	(5)
$\ln dist_{ij}$	-0.531	-1.235	-0.681	-2.422	-2.715
	(0.05)	(0.03)	(0.33)	(0.32)	(0.53)
Constant	17.58	25.17	20.45	35.87	38.67
	(0.39)	(0.37)	(2.95)	(2.88)	(4.74)
Fixed Effects?	No	Yes	Yes	Yes	Yes
Importer Interaction terms?	No	No	Yes	No	Yes
Exporter Interaction Terms?	No	No	No	Yes	Yes
F-test*	-	-	0.00	0.00	0.00
R^2	0.069	0.901	0.916	0.920	0.934
N	1482	1482	1482	1482	1482

Notes: Dependent variable is $\ln x_{ij}$, the log of bilateral shipment between OECD and BRICS countries. Column (2) to (5) includes origin and destination fixed effects. Interaction terms are bilateral distance interacted with importer and exporter dummy variables. Standard errors are in parentheses. All coefficients are significant at the five percent level. *P-value for joint test of significance of distance interaction terms. Details on data is provided in the appendix.

(2013). Section 4 describes the structural estimation method and identification strategy. Section 5 estimates the model and explores the effects of higher trade restrictions with two counterfactual analyses. Section 6 concludes.

2 Motivation

In order to illustrate variability in trade responses, I regress the log of shipments on bilateral distances in a fixed effects model. The specification is a simple gravity equation where the trade costs is represented with just bilateral distances. In order to capture the possibility of different elasticities for each importer, I interact distance with importer dummy variables in the gravity equation. The same data is used as in Section 5 and the data is described in the appendix.

The regression results, presented in Table 1, show that each importer has a different trade response. The inclusion of the distance and importer dummy interaction terms in column (3) does 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 rejects 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, we can attribute the different distance coefficients to different own-price elasticities of imports.

Column (4) of Table 1 shows that elasticities can also differ for each exporter. The F-test on the joint significance of the exporter interaction terms also fails to reject the null hypothesis. Column (5) presents the results when the distance terms are interacted with both exporter and importer dummy variables. These interaction terms are jointly significant. That the elasticities can differ by exporter should not surprise the reader since supply can also react differently to changes in trade costs. While allowing for the elasticities to vary on the demand and supply side will enrich the trade model, it can complicate the analysis. We will focus on a model that allows the elasticities of importers to vary and examine how the model differs from the standard trade model.

3 An Armington Trade Model with Translog Preferences

3.1 Theory

The theory is motivated via Armington preferences as in Anderson (1979): the model assumes Armington preferences over the goods differentiated by origin (Armington, 1969). 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 consumption depends on prices, and prices depend on iceberg trade costs. The point of the exercise is to minimally adjust the canonical Anderson and Van Wincoop (2003) framework to illustrate the implications of flexible parameterization of the representative consumers' preferences[7]. The exercise also allows us to use the Arkolakis et al. (2012) framework to understand welfare implications of less restrictive assumptions about demand side behavior[8].

The representative consumer's utility maximization problem generates an import demand and is expressed as its dual, the unit expenditure function. I represent the unit expenditure function with a translog functional form, which is a second-order approximation with respect to prices of an arbitrary expenditure function (Diewert, 1976). Flexible functional forms, like the translog form, do not impose any restrictions but are still consistent with the assumptions inherent in the approximated functions.

The translog expenditure function is defined as:

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

[7]One could posit other theories of bilateral trade (Eaton and Kortum (2002); Melitz (2003) and Chaney (2008)) but my purpose is to work from the Anderson and Van Wincoop framework.

[8]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. **?** also show that there can be different aggregate welfare results with different supply side assumptions, while still adopting a CES demand side structure. I introduced flexibility on the demand side to illustrate the benefits of parameter flexibility and examine the changes to welfare levels when trade costs change.

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, where n, k indexes the goods. The parameters in the translog function are analogous to those in the CES unit expenditure function[9]. 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 derivatives with respect to prices $\nabla_{p_{nj}p_{kj}}E_j$ are negative semidefinite. 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 4[10].

Applying Shephard's Lemma to equation (1), the import share equation

[9]The CES expenditure function is defined as $E_j = \left[\sum_{n}^{N}\left(\theta\tilde{p}_{nj}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$.

[10]It is a common issue that the curvature conditions of theoretical functions are not satisfied by the unrestricted translog function. I use the restrictions in Diewert and Wales (1988) because it maintains the flexibility of translog function, while achieving global concavity in prices. There are two alternative methods to impose concavity on the translog form. Restrictions can be placed on the translog function to impose global concavity but this might remove the flexibility of the form (Diewert and Wales, 1987). Conversely, restrictions can be placed at a single observation, which maintains the flexibility of the translog function but only imposes concavity locally (Ryan and Wales, 2000).

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:

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

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

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:

$$\varepsilon_{ij}^{Trans} = \frac{d \ln x_{ij}}{d \ln \tau_{ij}} = \frac{\beta_{ii}}{s_{ij}}. \tag{5}$$

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.

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, which 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 goods i and j:

$$\sigma_{ij} = \frac{\beta_{ij} + s_{ij}s_{jj}}{s_{ij}s_{jj}} \;\; \forall i, j \text{ and } i \neq j, \tag{6}$$

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

$$\sigma_{ii} = \frac{\beta_{ii} + s_{ii}^2 - s_{ii}}{s_{ii}^2}. \tag{7}$$

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 elasticities in the translog model are different from those in Novy (2013). While Novy has a model with differentiated product varieties, he uses a measure of extensive margin to simplify the estimation. The own-price elasticity of imports in his model is:

$$\varepsilon_{ij}^{Novy} = \frac{d \ln s_{ij}}{d \ln \tau_{ij}} = -\frac{\gamma g_i}{s_{ij}}, \tag{8}$$

where g_i is a measure of the extensive margins of the exporting country, and γ is a parameter from the restrictions Novy places on the translog function. The measures of extensive margins are taken from data so Novy essentially estimates a single parameter in his gravity estimation [11].

[11] It may not be suitable to use this measure of extensive margins given that it implicitly assumes each country is exporting the entire product range to every country. Whereas the numerator in equation (5) is an estimated parameter that varies with exporters, the numerator in Novy's own-price elasticity varies only by the extensive margin. Moreover, Novy develops his model assuming monopolistic competition. In a model with Armington goods, the extensive margin measure will be absent in equation (8) and variation in the elasticities will depend solely on the import share values.

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 captures 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 will be relatively inelastic.

For example, Australia is a large and relatively open country that exports about 75 percent of its production of goods. It can command a large market share in the New Zealand market because it is close-by and a small market. New Zealand is also remote and lacks access to other low costs suppliers. 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[12]. In the CES model, by

[12]The Armington assumption classifies the bundle of goods from a country as the national good so another way to interpret the inelastic U.S. demand for Australian imports is that within the American bundle of goods, there is one good that is highly substitutable with the Australian good.

contrast, the demand for Australian imports by New Zealand and the U.S. will be the same: the import demands of these two countries will react in the same fashion to an increase in trade costs and imports from Australia will decrease by the same proportion.

The own-price elasticity of imports also captures aspects of market competition. An exporter 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[13].

3.2 Model's Implications

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

$$W_j = 1 - \left(\frac{\lambda_{jj}}{\lambda'_{jj}}\right)^{1/\varepsilon}, \tag{9}$$

where λ_{jj} and λ'_{jj} are a country's expenditure on home goods before and after changes in trade costs, and ε is the elasticity of imports with respect to trade costs (or own-price elasticity of imports). In the CES model, $\varepsilon^{CES} = 1 - \sigma$ so there is a linear relationship between the welfare effects of a change in trade

[13] 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. They use firm level data to estimate the varying elasticities, while I will be estimating the elasticities from aggregate trade data.

costs and changes in openness $\left(\frac{\lambda_{jj}}{\lambda'_{jj}}\right)$.

In fact, the result in Arkolakis et al. (2012) is more general: one does not need to know the origin of the shock, whether it is a change in the trade costs with one trade partner or a proportional change across all partners, the formula summarizes the welfare effects of that shock[14]. These two variables 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).

For the ACR formula to hold, the trade model must have an important macro-level restriction — it must produce a CES import demand system. Such an import demand system means that the bilateral imports are only affected by changes to trade costs on that bilateral link, i.e. $\frac{d\ln x_{ij}}{d\ln \tau_{ij}} = 1 - \sigma$. This import demand system implies that 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 welfare formula in Arkolakis et al. (2012) does not apply in my translog gravity model. In this 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:

$$\varepsilon_{ik}^{Trans} = \frac{d\ln x_{ij}}{d\ln \tau_{kj}} = \frac{\beta_{ik}}{s_{ij}} \geq 0. \tag{10}$$

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.

[14]The effects of a change in trade costs with one partner versus a proportional change across all partners are different. With a change in trade costs with one partner, there will be a trade diversion effect, while there will not be one with the proportional change in trade costs. The formula applies in both cases because it captures the diversion of trade towards the country's home good.

The flexible import demand system is key to why this translog gravity model has a different welfare implication from Arkolakis et al. (2012). Other gravity models have incorporated a translog demand system but they still generate the Arkolakis et al. (2012) welfare result because these models produce a CES import demand system. Arkolakis et al. (2010) show that the ACR formula can summarize welfare changes in a model with translog form and firm-level varieties. They can obtain this result because they apply restrictions in Feenstra (2003) on the translog form, which impose additional structure creating a CES-like preferences[15]. Novy (2013) also has a translog gravity model with the Feenstra (2003) restrictions. Even though Novy does not examine if the ACR formula applies to his model, a simple check of the gravity equation shows that his restricted translog model conforms to a CES import demand system[16]. Thus, the Arkolakis et al. (2012) welfare result applies in Novy (2013): the model has the same welfare implications as other quantitative trade models.

Without a CES import demand system, there is no equivalent statistic or formula, like the ACR formula, that can summarize changes in welfare levels in the translog model. Welfare calculations have to done using counterfactual analyses. We can, however, expect that the welfare changes due to changes in trade costs in the translog model to be heterogeneous compared to the CES model. Heterogeneity in the changes of welfare levels is evident: importers in the translog model have varying own-price elasticities so the changes in welfare levels will not exhibit a clear linear relationship with a country's consumption

[15]The restrictions are on the substitution matrix of the expenditure function: a matrix of the cross partial derivatives of the expenditure function with respect to the prices of two goods. The matrix is composed of all β_{nk} parameters. The restrictions in Feenstra (2003) impose one value for the off-diagonal and one value for the diagonal elements. The substitution matrix for a CES expenditure function will have σ on the off-diagonal and zeroes on the diagonal.

[16]See equation 7 in Novy (2013).

of its home goods.

We can also expect that the welfare changes to be larger in the translog model. The magnitude of the welfare level changes depends largely on how the changes in the trade costs affect the expenditure function. The CES expenditure function only captures the direct effect of a change in trade costs on the price of the affected goods. In contrast, the translog expenditure function contains additional variables — the third variable on the RHS of equation (1) — that capture the indirect, or substitution, effects of a change in trade costs. As $\beta_{nk} \geq 0$ ($\forall n \neq k$), any change in trade costs will be amplified in the translog expenditure function since the direct and substitution effects move in the same direction. With the same income levels, an increase in trade costs causes a larger increase in the translog expenditure function, which results in larger welfare losses compared to the CES model.

4 Estimating Framework

4.1 Structural Estimation

The estimation method depends on how the structure is imposed in the model. Anderson and Van Wincoop (2003) show that the general equilibrium structure, specifically the market clearance conditions, is important in the trade model, and excluding the structure can create omitted variable bias in the estimation. On the other hand, applying the market clearance conditions to the model complicates the estimation because the new terms in the import demand introduces non-linearity in the model[17].

Several methods are used to deal with this issue, with fixed effects and non-

[17] When the market clearance conditions are applied, multilateral resistance terms are included into the import demand equation (Anderson and Van Wincoop, 2003). These multilateral resistance terms capture the effects of relative prices in the model but also introduces non-linearity in the estimation as the terms are a function of each other and trade costs.

linear estimation being the two most common[18]. With fixed effects methods, the non-linear terms are captured with fixed effects. With non-linear estimation methods, the non-linear 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 (2012). The MPEC approach guarantees full theoretic consistency of the fitted values and the estimated parameters[19]. Although the empirical procedure is conceptually similar to the non-linear least squares approach of Anderson and Van Wincoop (2003), it presents an advantage when conducting counterfactual analyses. The constraints define an operational general equilibrium that allows for a simple transition from the estimation 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 between the observed (z_{ij}) and fitted ($\hat{z}_{ij}$) trade values:

$$\min \sum_i \sum_j \left[z_{ij} - \hat{z}_{ij}\right]^2, \tag{11}$$

subject to the constraints implied in the model[20]. These constraints include a

[18]There is a 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.

[19]The MPEC is used to solve a Walrasian general equilibrium here and in Balistreri and Hillberry (2007), whereas the focus of MPEC estimation following Judd and Su (2012), has been on partial equilibria, and more typically Nash equilibria.

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

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 conditions 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:

$$y_i = p_i m_i \quad \forall i, \tag{12}$$

$$m_i = \sum_j \hat{s}_{ij} m_j \quad \forall i, \tag{13}$$

$$\ln E_j = \xi + \sum_{n=1}^{N} \alpha_n \ln \tilde{p}_{nj} + \frac{1}{2} \sum_{n=1}^{N} \sum_{k=1}^{N} \beta_{nk} \ln \tilde{p}_{nj} \ln \tilde{p}_{kj} \quad \forall j, \tag{14}$$

$$U_i E_i = y_i \quad \forall i. \tag{15}$$

Equation (12) defines the income of a country where y_i and m_i are the nominal and real income of the country i. Equation (13) defines clearance in the goods market. Equation (14) is the unit expenditure function, and equation (15) defines the utility of country i where U_i is the utility level.

In addition, certain assumptions and normalizations in the model are made to estimate the parameters. Following Balistreri and Hillberry (2007), the GE model is normalized such that the choice of endowment units equal the observed nominal income:

$$y_i = m_i \quad \forall i, \tag{16}$$

$$p_i = 1 \quad \forall i. \tag{17}$$

The constant term in the unit expenditure function (ξ) is assumed to equal one[21]. 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 shares in each importing country sums to one:

$$0 \leq s_{ij} \leq 1 \quad \forall i, j \tag{18}$$

$$\sum_{j}^{N} s_{ij} = 1. \tag{19}$$

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, E_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 (11) is defined by taking the log of import

[21] 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.

demand in equation (4):

$$\ln s_{ij} = \ln m_j + (1 - \sigma) \left[\ln \theta_i + \ln p_i + \ln \tau_{ij} - \ln P_j \right]. \quad (20)$$

Changes are made to the expenditure function and market clearance conditions to reflect those in the CES model[22]. The importer income coefficient is also restricted to one to be consistent with theory. The CES specification estimates the values of σ and θ_i, conditional on the trade cost specification.

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 or add a small value to the zeroes. Alternatively, one could use the pseudo-Poisson maximum likelihood approach set out by Santos Silva and Tenreyro (2006) but they do not provide a theoretical reason for the existence of zeroes in the data. With the translog model, zero trade flows are possible in the theory because countries do not consume that particular good and we can include the zeroes in the estimation[23].

Trade costs are 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

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

[23]It is also possible to assume a Poisson distribution for the error term in the estimation but it is not done here.

crossing national borders.

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 (12) to (15) 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 parameters are locked in while income and prices are freed up for the counterfactual analysis. Changes are made to trade costs in 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.

Standard errors are calculated using bootstrapping techniques for all the variables in the estimation. The uncertainty in our variable estimates is also carried into the counterfactual calculations so bootstrapped standard errors are also calculated for the counterfactual analyses[24]. For each iteration, a new bootstrap sample is drawn with replacement from the original sample. The process is repeated 1,000 times.

4.2 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.

While the translog form allows us to move away from estimating a single elasticity parameter, there is a challenge of separately identifying the variables

[24]In the trade literature, standard errors are usually not calculated for the counterfactual analyses but it should be.

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[25]. Anderson and Van Wincoop (2003) assume a value for σ in their post-estimation calculations. Balistreri and Hillberry (2007) impose the value $\sigma = 5$ pre-estimation, but this is without consequence to the estimation. Since the translog model does not contain the σ parameter, it is more sensible to impose a ρ value in our estimation. I impose $\rho = 0.267$ in estimation, which is a direct estimate of the distance elasticity of trade cost from freight costs data (Hummels, 2001). The value is also used in Novy (2013).

In the translog expenditure function, the own-price elasticity of imports is no longer restricted to be a single structural parameter. This flexibility, however, complicates 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, where N is the total number of national goods in the model[26]. The degrees of freedom and the efficiency of parameter estimates are greatly reduced compared to the CES specification.

Novy (2013) applies the restrictions in Feenstra (2003) to reduce the

[25] By imposing a structural parameter in the estimation, we are mixing calibration and estimation methods.

[26] If there are 50 goods in the sample, the 2500 observations are used to estimate 1326 parameters.

parameters in the substitution matrix, an $N \times N$ matrix of the β_{nk} parameters. 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):

$$\beta_{nk}^{Novy} = \frac{\gamma}{G}, \quad \forall n \neq k \tag{21}$$

$$\beta_{nn}^{Novy} = -\frac{\gamma}{G}(G-1). \tag{22}$$

Thus, the substitution matrix will only possess two values: one along the diagonal using equation (22) and one off the diagonal using equation (21). These restrictions place an *a priori* assumption on the substitutability of the goods: the same off-diagonal elements presupposes that each good is the same substitute to every other good. This assumption is similar to a CES assumption. It would be better to allow the data to inform us about the substitutability of the goods. By using the extensive margin (G) in the restrictions, Novy also implicitly assumes that each country exports the same number of goods to every trade partner.

These restrictions 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 simplify the model in such a way that aggregate trade flows can be used[27].

An alternative set of restrictions developed by Diewert and Wales (1988) is 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

[27] A fixed effects model is estimated with aggregate trade flows between 28 OECD countries.

degree of flexibility while still being consistent with the concavity assumptions required for the expenditure function.

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

$$B = -DD^T \tag{23}$$

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:

$$\beta_{nk} = \gamma b_n b_k, \quad \forall n \neq k \tag{24}$$

$$\beta_{nn} = -\gamma b_n \sum_{n \neq k} b_k, \tag{25}$$

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

5 Rising International Trade Restrictiveness

5.1 Estimation Results

The estimation model covers 39 countries consisting of 34 OECD countries and five BRICS countries in 2006[28]. The BRICS countries are included in the sample to make it a more representative data set. This sample expands the subset of OECD countries examined in Eaton and Kortum (2002) and Novy (2013). The 39 countries make up about 90 percent of the world's GDP in 2006. The data sources are discussed in the appendix.

Before discussing the results, there is a matter in the construction of the

[28] 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. The countries and their alpha-3 codes are listed in Table 2.

import share variables, which is the ratio of imports from country i (x_{ij}) and expenditure of country j (m_j). A country's expenditure, measured as the value of total imports, usually equals its income. There is, however, a discrepancy between the expenditure and income of a country because, for example, of the presence of non-traded service sectors or, in this case, an incomplete set of import partners. The discrepancy between expenditure and income figures is an issue in any estimation of the gravity model, but it becomes more important here[29]. In the translog estimation, the import shares equal one and that allows us to drop a share equation but that is not possible if income is larger than expenditure. The solution taken in this paper is to create an artificial measure of expenditure by aggregating a country's import values (including its own trade flows) and treating that as the country's expenditure.

The translog estimates of α_n and β_{nn} are presented in Table 2. The α_n parameters, which are common for all countries, inform us about the importance of a country's goods in the expenditure function. It is 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). β_{nn} is presented for each importer and these are used to construct the elasticities.

Estimates for the own-price elasticities and the border taxes are presented in Table 3. 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 -4.68. The CES elasticity of

[29] 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 need to take a stand on domestic trade flows.

Table 2: Parameter Estimates

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)

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

Table 3: Estimation Results

	(1) CES		(2) Translog		
Dependent Variable:	$\ln s_{ij}$		s_{ij}		
				Mean	Median
Own-price Elasticity (ε)	$(1-\hat{\sigma})$	-4.44	$\hat{\beta}_{nn}/\hat{s}_{nj}$	-4.68	-3.18
		(0.13)			
Substitution Elasticity (σ)	$\hat{\sigma}$	5.44	$\hat{\sigma}_{ij}$	1.59	1.39
		(0.13)			
Border Tax (δ)		0.64		2.22	
		(0.04)		(0.74)	
N		1521		1521	

Notes: Bootstrapped standard errors are in parentheses. The coefficients are significant at the one percent level.

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 the border tax (δ). The CES 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 δ estimate is 2.22, which means that there is a 817 [$= \exp(2.22) - 1$] percent ad valorem tariff equivalent on foreign goods[30]. All estimates of elasticities and border tax are significant at the one percent level.

The average own-price elasticity estimated in the translog model closely matches the CES estimate. Behind the average own-price elasticity, there is a distribution of elasticities with a median of -3.18. Some bilateral pairs have very elastic trade relationships, which creates a heavy leftward skew in the

[30] The large border tax estimate in the translog model can be explained by a lack of variation in the home consumption variable. In the data, each country consumes only one home good while in Anderson and Van Wincoop (2003), each North American region consumes at least ten home goods. The large border tax can be a result of a large non-tradeable sector in each country.

distribution[31]. There are fifteen pairs (or the top one percent) with 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.

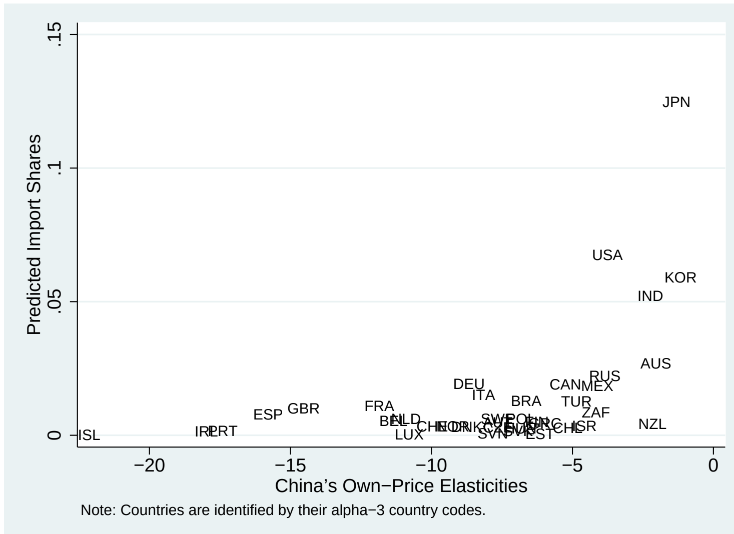
Substitution elasticities are calculated for all country pairs with positive predicted import shares using $\hat{\beta}_{ij}$ and $\hat{s}_{ij}$. The average and median substitution elasticities are 1.59 and 1.39 respectively. Positive elasticities indicate that both goods in each bilateral pair are substitutes, a result that is consistent with the Armington assumption. Most of the country pairs have elasticities below 10, with over 90 percent having elasticities below 2, and only four country pairs have an elasticity above 10[32]. This implies that most pairs, despite being substitutes as assumed in the Armington model, are not strong substitutes.

It is informative to examine the bilateral elasticities of a large country, say China, to better understand its relationship with its trading partners. Figure 1 plots the own-price elasticities of China's import demand against the predicted import share, or the market share each country has, in China.

The own-price elasticity can be related to country size. China is more likely to have an inelastic demand for a good from a large country, like the U.S. (USA), Canada (CAN) and Germany (DEU). With the Armington assumption, each good can be considered to be a composite national good. Large countries that have a broad manufacturing base will have composite national goods that are less substitutable compared to the Chinese good[33].

[31]See Figure A.1 in the appendix for the distribution of the bilateral own-price elasticities.
[32]See Figure A.2 in the appendix for the distribution of the Allen elasticities.
[33]Another argument for the inelastic demand for goods from large countries is these countries can achieve scale economies and sell their good at a lower f.o.b. price compared to smaller countries, thus capturing a larger market shares. This argument is plausible but I do not make it here because the model does not contain scale economies.

Figure 1: Bilateral Own-Price Elasticities of China's Imports



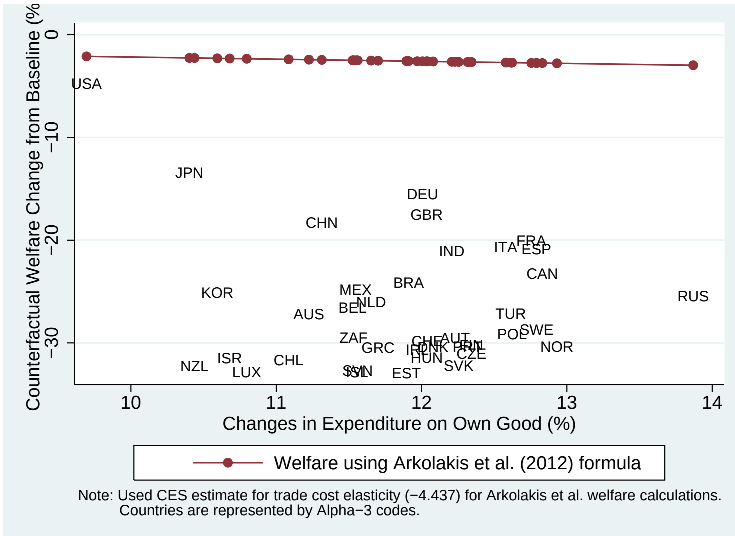
Notes: The bilateral own-price elasticities of China's imports are plotted against the predicted import shares in China. Import goods are identified by their alpha-three country codes.

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. Even China has a relatively inelastic demand for goods from New Zealand, a small country, because of it relative proximity. Thus, neighboring countries can capture bigger market shares, and face relatively inelastic demand.

5.2 Counterfactual Analysis 1: Rising Protectionism

The first counterfactual analysis imagines a scenario where each country becomes more protectionist. 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 both counterfactual analyses, the f.o.b. output from the U.S. is arbitrarily chosen as

Figure 2: Welfare Changes from Increasing Trade Barriers



Notes: 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. Countries are represented by alpha-3 country codes.

the numeraire. I compare the welfare effects from the translog model to those using the ACR formula[34].

The change in the welfare levels when trade costs increase can happen through two channels: a change in real income and a change in the cost-of-living index. When trade costs increase, consumers substitute between goods and their prices change, thus affecting the cost-of-living index. In my model with an endowment economy, changes in trade costs will not affect wages and in turn, real income ($w_i L_i$) will not change. Nominal income changes because the price of the home good changes.

The 50 percent increase in the trade costs is performed for each country

[34] The changes in welfare levels are calculated based on equivalent variations, where the point of reference for the counterfactual welfare levels is the benchmark equilibrium calculated in the previous subsection.

separately, while keeping the other countries at status quo. The changes to welfare levels are plotted in Figure 2 for brevity but all the counterfactual results, together with the changes to the cost of living and income, are presented in Table A.1 in the appendix. The changes to the welfare levels are significant at the one percent level. A rise in protectionism has a varied impact on the welfare of countries: welfare losses range from a small 4.8 percent decrease in welfare for the U.S. to a large 32.8 percent decrease for Iceland. The variation in the welfare losses can be explained by the expenditure on the home goods, which recalls the welfare result in Arkolakis et al. (2012). The home good expenditure is influenced by the size of the country and its weight in the expenditure function.

Country size is negatively related to the welfare loss from higher trade barriers. Small countries like Estonia, Iceland, Luxembourg, Slovak Republic, and Slovenia suffer the largest welfare losses, while large countries like China, Germany, Japan, the United Kingdom, and the U.S. suffer the smallest welfare losses. This is because country size is indicative of whether the country needs 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.

Conversely, welfare losses are mitigated by the importance of a country's good in the expenditure function, which is determined by α_n. We can see in Table 2 that the U.S. has the largest weight, followed by Japan, then China. A large weight means that the good has a large demand compared to other goods. When the importing country increases its trade barriers, local consumers substitute to the home good, which pushes up the price of the home goods. If the country has a large weight, other countries will continue demanding this good despite the higher price, further driving up the prices. The higher domestic prices increase nominal income, and this will dampen the welfare losses from higher trade barriers. For example, Japan experience a large increase of 3.47 percent in nominal income but a small welfare loss of 13.41 percent. In contrast, Estonia has a small weight in the expenditure function, and subsequently a smaller increase in nominal income and the largest decrease in welfare levels.

The changes in the welfare levels are plotted against the changes in the expenditure on home goods in Figure 2. We can see that changes in welfare levels and expenditure on home good are not linearly related. As a comparison, welfare changes are calculated according to the ACR formula using the CES estimate of the own-price elasticity, and represented by the line in Figure 2[35].

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 those calculated with the ACR formula, which exhibit little variation and have a strict linear relationship with changes in home good expenditure.

The range of the welfare losses also differ vastly between the counterfactual calculations and the ACR formula. While home good expenditure increased between 10 to 14 percent, the variation in welfare calculations from the formula is small: the 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 counterfactual welfare losses are larger and more heterogeneous: the average welfare loss in the translog model is 27 percent with a minimum loss of 4.75 and a maximum loss

[35]Since the ACR formula summarizes the welfare changes in Novy (2013), these welfare calculations can also be thought of as counterfactual calculations in that model.

of 33 percent. Compared to the translog model, the welfare losses according to the ACR formula are eight times smaller for China, France, India, and the U.K., and ten times smaller for Australia, Brazil, Canada and Russia.

The large difference in welfare losses between the CES and translog models is due to the varied trade responses through the bilateral substitution elasticities in the translog model[36]. 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. On average, the substitution elasticities in the translog model are smaller in magnitude, i.e. the bilateral trade relationships are relatively more inelastic, compared to the CES model. The inelastic trade relationships ensure that the country continues to import certain goods even after the increase in import barriers. As a result, the country's costs of living is higher, and welfare levels lower. The importer-specific trade elasticities in the translog model also creates the heterogeneous welfare losses. Without a constant elasticity of substitution, welfare changes in the translog model cannot be summarized by one sufficient statistic.

5.3 Counterfactual Analysis 2: Behind the Great Wall

For the second counterfactual analysis, I propose a scenario where China is removed from the world trade system. China's participation in the world markets has reshaped international trade and more importantly, has raised

[36]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.

the income and welfare of its citizens and its trading partners. The effects of China's participation were amplified by China's accession into the World Trade Organization (WTO). It is therefore revealing to examine the effects of removing China from world markets.

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 $dist'_{China,j} = dist_{China,j} \times 100 \ \forall j \neq China$)[37]. Any trade with China will occur at a high cost.

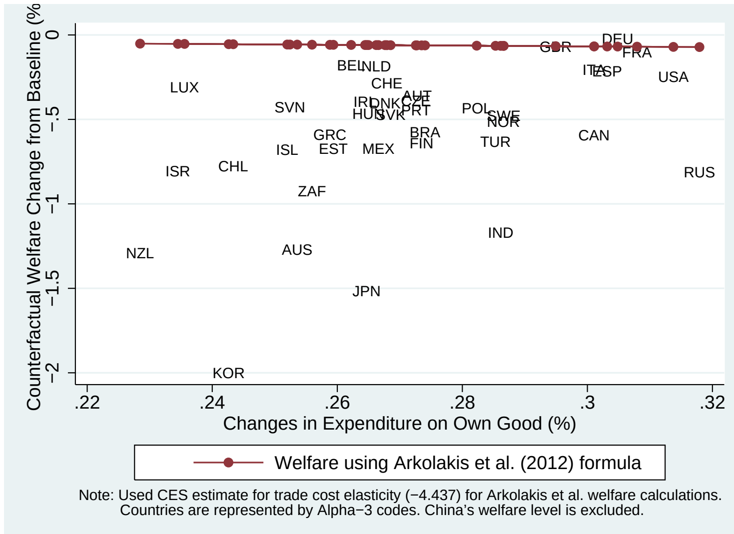
As expected China suffers the most when it stops trading; its welfare level drops by 61 percent[38]. China has to produce its own goods when it stops trading with the world. Chinese consumers will decrease their demand for expensive imports and substitute to the home good. Thus, China's consumption of its own goods increases by 69 percent, which puts an upward pressure on domestic prices and increases the cost of living. The large increase in the cost of living is a major reason why China experiences such a large welfare loss. Clearly it is not in China's interest to retreat from the world.

Welfare levels will fall for all countries when a major manufacturing country like China retreats from the world trading system. China's trade partners 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. The changes to welfare levels of China's trade partners are plotted in Figure 3. These welfare losses are small and they indicate that even though countries might suffer welfare loss from not trading with China, the consequences are not catastrophic.

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

[38]Table A.2 in the appendix contains the changes to the welfare levels and China's imports from its partners.

Figure 3: Welfare Losses when China stops Trading



Notes: 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. Countries are represented by their alpha-3 country codes.

The responses of China's trade partners to the higher trade barriers are captured by their respective own-price elasticity, as shown in Figure 1. Iceland, Ireland, Portugal, Spain, and United Kingdom, at the bottom left corner of the figure, have the most elastic trade relationships with China. These countries suffered the largest decrease of more than 300 percent in their trade with China. Conversely, countries at the right of the figure like Australia, Korea, Japan and New Zealand have relatively inelastic trade relationships and China did not decrease its imports from these countries compared to other countries. As the counterfactual simulation does not put China fully into autarky, China still trades with some countries, which suggests that the goods from these countries are not as substitutable as the other goods.

Welfare losses are also calculated with the ACR formula using the CES elasticity estimate. Aside from China, the welfare losses from the counterfactual analysis and the welfare formula are plotted in Figure 3 against the changes in the expenditure on home goods. 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. It is noteworthy that the ACR 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 international trade flows among OECD and BRICS countries. 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 two counterfactual analyses. First, 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. Second, China is removed from the trading system and it suffers the largest welfare loss. Even though China is an important player in the global trading 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 larger and heterogeneous. The ACR formula applies to a class of models that summarize trade responses via a single parameter. Once we allow elasticities to vary across importers, which are more representative of the data, the formula is no longer a good measure of welfare.

This paper complements the work by Melitz and Ottaviano (2008), Feenstra and Weinstein (2010), and Novy (2013) 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. Future work can enrich the flexible demand system with richer supply-side details in the trade model.

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Data Appendix

Nominal GDP: World Bank's World Development Indicators (WDI).

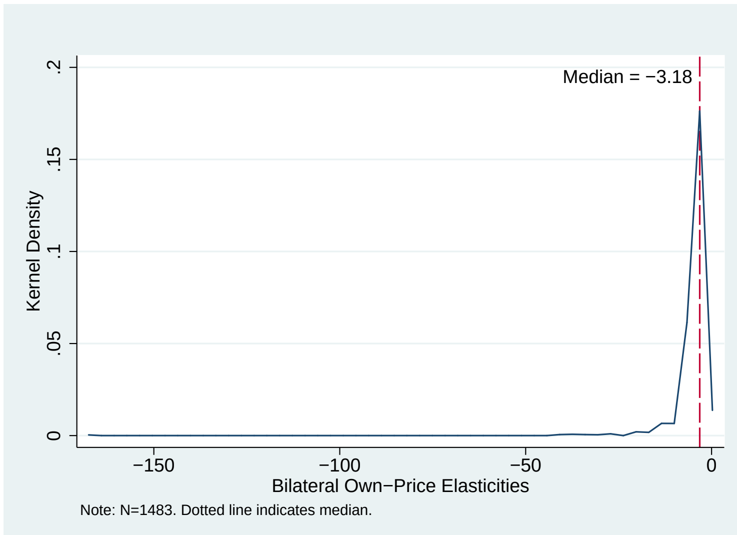
Distances: CEPII gravity data set. Distances are measured as the population weighted average of distance of the largest cities between countries. Distances are normalized by the shortest distance pair (Luxembourg-Luxembourg).

Home Consumption: = 1 if importing country consumes its own good.

Aggregate Bilateral Trade: values reported to the UN COMTRADE system. Import flows are used but if missing, they are supplemented with export flows reported by sending country. A country's own trade flow, not reported in the data, is assumed to be the difference between its GDP and the total exports to all countries in UN COMTRADE. The service component of home consumption is removed using the ratio of service in the GDP, taken from the World Development Indicators.

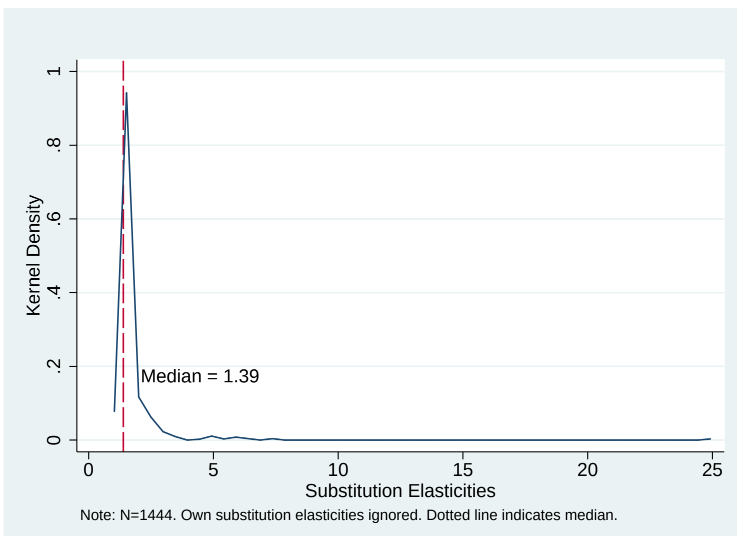
Results Appendix (Not for Publication)

Figure A.1: Distribution of Bilateral Own-Price Elasticities



Notes: 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.

Figure A.2: Distribution of Allen Substitution Elasticities



Notes: The mean is 1.59 and the median is 1.39. The long right tail is explained by four bilateral pairs with elasticities above 10.

Table A.1: Rising Protectionism: Changes to Welfare, Income and Cost of Living

	Percentage Change (%)				Percentage Change (%)				Percentage Change (%)		
Country	Welfare	Cost of Living	Nominal Income	Country	Welfare	Cost of Living	Nominal Income	Country	Welfare	Cost of Living	Nominal Income
Australia	-27.17	37.30	0.66	Greece	-30.44	44.12	0.25	Norway	-30.33	43.91	0.26
	(1.25)	(2.32)	(0.30)		(0.54)	(1.12)	(0.12)		(0.62)	(1.27)	(0.13)
Austria	-29.55	42.55	0.43	Hungary	-31.40	46.07	0.20	Poland	-29.15	41.79	0.46
	(0.65)	(1.31)	(0.22)		(0.35)	(0.74)	(0.20)		(0.73)	(1.45)	(0.23)
Belgium	-26.55	37.29	0.83	Iceland	-32.83	48.91	0.02	Portugal	-30.33	43.87	0.23
	(1.02)	(1.91)	(0.83)		(0.09)	(0.20)	(0.01)		(0.55)	(1.13)	(0.00)
Brazil	-24.12	32.93	0.86	India	-21.07	28.06	1.08	Russia	-25.46	35.13	0.73
	(2.04)	(3.54)	(0.00)		(1.96)	(3.27)	(0.00)		(1.55)	(2.79)	(0.36)
Canada	-23.26	32.15	1.41	Ireland	-30.66	44.53	0.22	Slovak Rep	-32.19	47.65	0.12
	(2.65)	(4.65)	(0.71)		(0.45)	(0.94)	(0.11)		(0.21)	(0.46)	(0.12)
Chile	-31.68	46.58	0.14	Israel	-31.47	46.11	0.13	Slovenia	-32.71	48.70	0.06
	(0.41)	(0.88)	(0.07)		(0.39)	(0.82)	(0.00)		(0.11)	(0.25)	(0.06)
China	-18.30	25.79	2.77	Italy	-20.64	28.27	1.79	South Africa	-29.47	42.14	0.24
	(2.51)	(3.85)	(0.00)		(1.73)	(2.79)	(0.90)		(1.14)	(2.28)	(0.12)
Czech Rep	-31.03	45.37	0.26	Japan	-13.41	19.49	3.47	Spain	-20.87	28.15	1.40
	(0.41)	(0.86)	(0.26)		(2.02)	(2.80)	(0.00)		(1.60)	(2.60)	(0.70)
Denmark	-30.39	44.08	0.30	Korea	-25.08	34.77	0.97	Sweden	-28.70	40.89	0.45
	(0.53)	(1.09)	(0.15)		(1.48)	(2.65)	(0.48)		(0.85)	(1.67)	(0.00)
Estonia	-32.92	49.12	0.03	Luxembourg	-32.82	48.94	0.05	Switzerland	-29.83	43.08	0.40
	(0.09)	(0.19)	(0.02)		(0.09)	(0.19)	(0.00)		(0.77)	(1.58)	(0.20)
Finland	-30.19	43.61	0.25	Mexico	-24.81	34.55	1.17	Turkey	-27.16	38.10	0.59
	(0.63)	(1.29)	(0.25)		(1.77)	(3.18)	(0.58)		(1.13)	(2.14)	(0.30)
France	-20.01	27.51	2.00	Netherlands	-26.03	36.42	0.91	United Kingdom	-17.52	24.02	2.29
	(1.91)	(3.07)	(4.99)		(1.08)	(1.99)	(0.45)		(1.92)	(2.94)	(1.15)
Germany	-15.52	22.30	3.32	New Zealand	-32.23	47.71	0.11	United States	-4.75	15.98	
	(1.04)	(1.53)	(9.96)		(0.24)	(0.52)	(0.05)		(0.98)	(1.20)	

Notes: 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 for changes to welfare levels and cost-of-living are significant at the one percent level. Most counterfactual results for real income changes are significant at the five percent level, except for Czech Republic, Estonia, Finland, France, Germany, Hungary, Slovak Republic and Solvenia.

Table A.2: Changes to Welfare and Imports: China Behind a Great Wall

	Percentage Change (%)			Percentage Change (%)			Percentage Change (%)	
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)

Notes: 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.