GEPPML: General Equilibrium Analysis with PPML*

James E. Anderson
Boston College and NBER

Mario Larch
University of Bayreuth

Yoto V. Yotov
Drexel University

November 21, 2017

Abstract

We develop a simple procedure for general equilibrium (GE) comparative static analysis of gravity models. Non-linear solvers are replaced by (constrained) regressions using theoretical properties of the Poisson Pseudo-Maximum Likelihood (PPML) estimator. Our GEPPML procedure can readily be implemented in any software capable of estimating constrained Poisson models. The procedure accommodates calibrated as well as estimated trade costs while using the estimation power of structural gravity to generate general equilibrium comparative statics. Using GEPPML, we quantify the effects of a hypothetical removal of all international borders while preserving the impact of geography on trade. We find that trade liberalization has reaped at most half the potential world gains from trade in 2002 manufacturing. A complementary counterfactual experiment simulates the removal of the border between Canada and US, thus contributing to the famous "border puzzle" literature in a multi country setting.

JEL Classification Codes: F10, F14, F16
Keywords: International Borders, GEPPML, Structural Gravity, General Equilibrium Effects, Counterfactuals, Asymmetric Trade Liberalization

*We thank João Santos Silva and seminar participants at the Economic Research and Statistics Division of the WTO and at the ifo Institute, and conference participants at the 2015 European Trade Study Group meetings (Paris), the Panel Data Workshop on International Trade (Amsterdam), the 2016 Spring Midwest Meetings in International Trade, the 2016 North American Meeting of the Econometric Society, and the 2016 European Meeting of the Econometric Society for useful comments and suggestions. Yotov is grateful to the members of the CESifo group for their hospitality during his stay at the ifo Insitute in 2015. All errors are our own.

Contact information: Anderson–james.anderson@bc.edu; Larch–mario.larch@uni-bayreuth.de; Yotov–yotov@drexel.edu.

1 Introduction

At a time when globalization has become a derogatory term and hypothetical simulations of reversion to autarky attract attention as relevant policy experiments, better measures and methods of measurement of gains from trade are more important than ever. In this paper we evaluate the impact on trade and welfare when all international borders are removed and geography is the only impediment to trade. In doing so, we make three contributions to the recent literature on measuring gains in models with gravity-type structure. First, we offer a novel procedure to perform general equilibrium comparative static analysis of gravity models with the Poisson Pseudo-Maximum-Likelihood (PPML) estimator, which we label *GEPPML*. Second, we develop a hybrid procedure that combines the nice estimation and predictive properties of the gravity model with a calibration approach to deliver *"estibrated"* trade costs that match the data perfectly. Third, we propose a robust structural estimating gravity equation that delivers partial equilibrium estimates of the effects of *international borders vs. geography.*

Our comparative static contribution is a method to estimate general equilibrium counterfactuals with PPML (GEPPML). Structural gravity implies that the ratio of predicted bilateral trade to its benchmark frictionless flow is equal to a power transform of the ratio of bilateral trade cost to the product of inward and outward multilateral resistances. The multilateral resistances can be obtained as the solution to a non-linear pair of equation systems derived under the theoretical assumptions from global market clearance for each country's sales and meeting each country's budget constraint. Fally (2015) shows that when gravity is estimated with Poisson Pseudo-Maximum-Likelihood, as suggested by Santos Silva and Tenreyro (2006), the estimated fixed effects are exactly equal to the multilateral resistances (MRs) that satisfy the equation system.

The GEPPML procedure that we propose capitalizes on and crucially depends on the theoretical PPML property to match the structural MR terms to the estimated importer and exporter fixed effects. However, importantly, our methods can be implemented with any underlying vector of trade costs, regardless of how this vector has been obtained. Thus, as we demonstrate below, GEPPML can be used to perform comparative static analysis in combination with any other estimator that is believed to perform better in obtaining the estimates of the trade cost vector. In sum, GEPPML uses a *theoretical* property that only holds for PPML, however GEPPML can be implemented with *any* given trade costs vector.

GEPPML has some advantages over alternative methods of measuring gains from trade. Quantitative general equilibrium trade policy analysis imposes both estimation (of key parameters) and computation (of counterfactual equilibria) burdens on the analyst and his readers. A typical counterfactual comparative static exercise using gravity is to change some bilateral friction, e.g. remove a tariff, and then calculate the effects on trade flows and other variables of interest. The partial effect is based on the estimated bilateral friction, e.g. the percentage reduction in buyers' price times the trade elasticity. The general equilibrium impact requires the new counterfactual multilateral resistances, typically solved from the equation system with a nonlinear solver. Our alternative GEPPML method is a more readily accessible way to generate the general equilibrium comparative statics of gravity models. Another benefit is the combination of statistical with economic theoretic intuition in interpreting results. The estimated fixed effects (and their changes) provide traditionally strong fit to the data (under the PPML structure) along with satisfying equilibrium market clearance and budget constraints.

We derive our procedure of the comparative statics of gravity models in conditional general equilibrium, the Modular Trade Impact of Head and Mayer (2014), as well as the full general equilibrium impact when endowments are fixed but sellers' prices change (Head and Mayer (2014)'s General Equilibrium Trade Impact), such as in the Ricardian Eaton-Kortum model (Eaton and Kortum, 2002) and the Armington-CES model of Anderson and van Wincoop (2003). Multi-sector applications beyond the scope of this paper can similarly use GEPPML to calculate Modular Trade Impacts for each sector that nest in any compatibly separable inter-sectoral general equilibrium production model. This includes most applied general equilibrium models.[1]

The second contribution is a hybrid combination of GEPPML and the 'exact hat' algebra calibration methods of Dekle, Eaton and Kortum (2007, 2008).[2] Our main analysis differs quantitatively from the usual applications of Dekle, Eaton and Kortum (2007, 2008) in basing calculations on fitted (predicted) trade flows rather than observed trade flows, with the presumed advantage of controlling for measurement error in the trade flow data. We propose a hybrid "estibrating" procedure[3] that obtains estimates of some key trade cost components but also treats the gravity error term as a component of trade costs, thus calibrating the trade cost vector to fit the data. We demonstrate that our methods deliver results identical to those from Dekle, Eaton and Kortum (2007, 2008) when fitted trade values are replaced with observed values. An important difference between the two procedures is that GEPPML delivers trade cost response elasticities for specific variables/policies of interest and with the same data to which the comparative statics are applied. Thus for example an RTA elasticity estimated from the base cross-section or panel data (as for examples in Egger et al., 2011 or Anderson and Yotov, 2016) can be used in an RTA counterfactual experiment with the hybrid model that includes the gravity error term as a calibrated trade cost component.[4]

Our contribution on the estimation front is to propose a robust gravity specification that distinguishes between the effects of geography (distance and contiguity) versus all other forces that drive a wedge between domestic and international trade flows. The econometric gravity model delivers upper-bound border estimates because, by construction, our border gravity variables control for and absorb all forces that differentially affect international vs. internal

[1]See for a further discussion of extending our procedure beyond the endowment environment Appendix A.

[2]Head and Mayer (2014) provide Stata code solving the multilateral resistance terms via contraction mapping for use in such exercises. Costinot and Rodríguez-Clare (2014) review the related literature.

[3]We borrow the term "estibrate" from Balistreri and Hillberry (2005) who use the Anderson and van Wincoop (2003) gravity framework to argue that structural estimation with proper structural and parametric restrictions can be viewed as calibration. Our methods are consistent with the analysis, recommendations, and conclusions from Balistreri and Hillberry (2005). However, our use of the term "estibration" is different. Specifically, here it refers to the fact that the estimates of the bilateral trade costs that we will obtain and use in the counterfactual analysis fit the data perfectly, just as with calibrated trade costs.

[4]A potential advantage of the "estibrated" method for counterfactual analysis is that the error term in cross-section gravity estimations may be carrying systematic information about trade costs.

trade while controlling for geography. These include preference differences and differential internal geography along with cross-border frictions.[5] In the main analysis, we obtain an average border effect across all countries in our sample in a cross-section setting. We also experiment by eliminating pair-specific borders between the US and Canada, an elaboration of the analysis of McCallum (1995) and Anderson and van Wincoop (2003) in multi-country setting with intra-national trade flows.

We use GEPPML to perform a hypothetical experiment that removes all international borders while preserving the effects of geography on trade in manufactures for 40 countries and a rest-of-world aggregate over the period 1990-2002. Our analysis suggests that, all else equal, international borders decrease trade by an average of 79 percent (std.err. 2.575). In addition, we find that the gains from removing all international borders while keeping the effects of geography will result in welfare gains that vary widely between 4.8 (for US) and 40.3 percent (for Bolivia). An important result of our analysis is that a multilateral removal of all international borders will benefit poorer and developing countries disproportionally more.

Interestingly, our results of removing all international borders are similar in magnitude to the indexes from Costinot and Rodríguez-Clare (2014), who measure a move from autarky to current trade (liberalization) levels. This similarity holds more or less for all countries that enter our sample and the sample of Costinot and Rodríguez-Clare (2014). Our estimates suggest that by 2012 the world enjoyed at most half of the possible gains from trade and trade liberalization.[6] Hence, there is significant scope for further gains from trade in the

[5]The estimation specifications that we employ to obtain our main partial equilibrium estimates can be refined further by taking advantage of identification of the time dimension in a panel setting, by using alternative estimators, or by introducing additional explanatory variables that will control for specific trade liberalization and globalization forces. However, in order to keep the analysis simple and to emphasize the methodological contribution of our work we leave such refinements for future research.

[6]We say that the world has enjoyed *at most* half of the gains from trade, because we are comparing our results with the scenario from Costinot and Rodríguez-Clare (2014) that generates the largest gains from trade. In this scenario they allow for multiple sectors with intermediates and perfect competition and obtain similar magnitudes as we do. Hence, going back to autarky from observed levels of trade and removing all international borders from observed levels of trade lead to similar effects, and the total trade from gains effect from autarky to removing all international borders would be the sum of the two effects. In their one-sector experiment with perfect competition, Costinot and Rodríguez-Clare (2014) obtain about a fifth of the size

future. We also demonstrate as a check on our method that the GE indexes that we obtain with a simple loop in Stata are identical to the corresponding numbers obtained by solving the non-linear gravity system in Matlab.

We also employ GEPPML to investigate the effects of the removal of the international border between the US and Canada. We find that Canada sees the largest gains, distributed both on producers and consumers, while the modest gains for the US fall only on producers. Specifically, we find that exports increase most strongly for Canada with 52 percent, while total exports of the US increase by 19 percent. This is in line with findings of Anderson and van Wincoop (2003) as well as the intuition that smaller countries gain more than larger ones from trade liberalization. The biggest welfare gains with a 34 percent increase of real GDP are also for Canada, split between producers and consumers roughly about 60:40. The gains of 0.5 percent for the US are modest and go to US producers only. We also conduct an asymmetric experiment, where we only remove the border on Canadian exports to the US. The findings from this analysis emphasize the differential implications of trade policy for producers and for consumers, and can be viewed as a classic example of how, by serving a given group (i.e., the Canadian producers), policy makers who adopt mercantilist trade policies may hurt overall welfare in the economy relative to symmetric trade liberalization.

The rest of the paper is organized as follows. Section 2 reviews the structural gravity model and its empirical treatment and discusses the relationship between the structural gravity terms and the corresponding fixed effects from the empirical gravity equation. Section 3 describes our simple 3-step GEPPML procedure to obtain the general equilibrium effects of trade policy and changes in trade costs with the PPML estimator. In Section 4 we simulate a hypothetical scenario that removes all international borders to trade while preserving the effects of geography. Section 4.1 presents results that are based on an estimated trade cost vector. Section 4.2 uses "estibrated" trade costs. Section 4.3 investigates the effects of the removal of the international border between the US and Canada. Section 5 concludes. Fi-

of the effects. Adding multiple sectors, but not allowing for intermediates, the effects are about half the size.

nally, in appendices, we provide a Stata sample code that implements our procedures, discuss extensions beyond the endowment economy, provide figures that compare our approach with results from a non-linear solver, solve the system in changes, as well as provide additional results for our US and Canada counterfactual.

2 Structural Gravity with Fixed Effects

Anderson (1979) derives the first structural gravity model of trade under the assumptions of identical Constant Elasticity of Substitution (CES) preferences across n countries for national varieties differentiated by place of origin (Armington, 1969):[7]

$$\begin{aligned} X_{ij} &= \left(\frac{t_{ij}}{\Pi_i P_j}\right)^{1-\sigma} Y_i E_j, && (1)\\ P_j^{1-\sigma} &= \sum_i \left(\frac{t_{ij}}{\Pi_i}\right)^{1-\sigma} Y_i, && (2)\\ \Pi_i^{1-\sigma} &= \sum_j \left(\frac{t_{ij}}{P_j}\right)^{1-\sigma} E_j, && (3)\\ p_j &= \frac{Y_j^{\frac{1}{1-\sigma}}}{\gamma_j \Pi_j}. && (4) \end{aligned}$$

Here, X_{ij} denotes the value of shipments at destination prices from region of origin i to region of destination j. The order of double subscripts denotes origin to destination. E_j is the expenditure at destination j from all origins and Y_i denotes the sales at destination prices from i to all destinations. $t_{ij} \geq 1$ denotes the variable trade cost factor on shipments of goods or services from i to j, σ is the elasticity of substitution across varieties, and $\gamma_j > 0$ is the CES share parameter.[8]

[7] Anderson (2011) and Costinot and Rodríguez-Clare (2014) offer discussions of alternative microfoundations for structural gravity. Allen, Arkolakis and Takahashi (2014) discuss the uniqueness and existence properties of a wide class of structural gravity models.

[8] γ_j can bear different interpretations, e.g. it can be interpreted as a technology parameter depending on the underlying microfoundations of the structural gravity setting. We refer the reader to Hillberry et al. (2005) for an insightful discussion and analysis of the importance of the preference parameters for calibration results in the Armington gravity model.

P_j is the inward multilateral resistance (IMR), which aggregates the incidence of trade costs on consumers in each country, and also the CES price index of the demand system. Π_i is the outward multilateral resistance (OMR), which from (3) aggregates i's outward trade costs relative to destination price indexes. Multilateral resistance is a conditional general equilibrium concept, since $\{\Pi_i, P_j\}$ solve equations (2)-(3) for given $\{Y_i, E_j\}$. Note also that (2)-(3) solves for $\{\Pi_i, P_j\}$ only up to a scalar. If $\{\Pi_i^0, P_j^0\}$ is a solution then so is $\{\lambda\Pi_i^0, P_j^0/\lambda\}$. Therefore, a normalization of one of the multilateral resistances is needed in order to obtain a unique solution for (2)-(3).[9]

Finally, equation (4) is derived from the market clearance:

$$Y_i = \sum_j X_{ij} = \sum_j \left(\gamma_i p_i t_{ij}/P_j\right)^{1-\sigma} E_j = \left(\gamma_i p_i\right)^{1-\sigma} \sum_j \left(t_{ij}/P_j\right)^{1-\sigma} E_j \quad \text{for all} \quad j, \tag{5}$$

where p_i is the exporter's supply price of country i. Using Equation (3) leads to Equation (4).

Gravity equations are recommended to be estimated with importer and exporter fixed effects by Feenstra (2004), a recommendation followed by most of the subsequent literature. In addition, many recent papers follow the recommendation of Santos Silva and Tenreyro (2006) who argue in favor of the PPML estimator for gravity regressions in order to account for heteroskedasticity and to take advantage of the information contained in the zero trade flows. Taking these considerations into account, many recent studies employ a version of the following empirical gravity model:

$$X_{ij} = \exp\left(\mathbf{T}_{ij}\boldsymbol{\beta} + \pi_i + \chi_j\right) \times \epsilon_{ij}. \tag{6}$$

Here, $\mathbf{T}_{ij}$ is the vector of trade cost variables, $\boldsymbol{\beta}$ is a vector of coefficients, ϵ_{ij} is an error term, assumed to be independent of the regressors, with conditional expectation equal to one. The treatment of the error term as additive or multiplicative does not, in principle,

[9] See Anderson and Yotov (2010) for detailed discussions of the multilateral resistances.

affect the implementation of the GEPPML procedure. However, ϵ_{ij} enters Equation (6) multiplicatively because this treatment will enable us to implement our hybrid method to construct "estibrated" trade costs.

Importantly we note that, while most PPML applications in the literature use an additive error term, the multiplicative error term treatment is perfectly valid too. Santos Silva and Tenreyro (2006) show on pp. 644 that $y_i = \exp(\mathbf{x}_i\boldsymbol{\beta})+\varepsilon_i$ can be expressed as $y_i = \exp(\mathbf{x}_i\boldsymbol{\beta})\eta_i$, with $\eta_i = 1 + \varepsilon_i/\exp(\mathbf{x}_i\boldsymbol{\beta})$ and $E[\eta_i|x] = 1$. Further, they state in footnote 7 that "Whether the error enters additively or multiplicatively is irrelevant for our purposes." (p. 643). In fact, this observation goes back to Wooldridge (1992): "Another argument for defining economic quantities in terms of $E(y|\mathbf{x})$ is that it circumvents the issue of whether the "disturbances" in a model are additive or multiplicative. When $y \geq 0$ and interest centers on $\mu(\mathbf{x}) \equiv E(y|\mathbf{x})$, the disturbances can be multiplicative or additive: The models

$$y = \mu(\mathbf{x}) + \varepsilon, \quad E(\varepsilon|\mathbf{x}) = 0, \tag{7}$$

$$y = \mu(\mathbf{x})\eta, \quad \eta \geq 0, \quad E(\eta|\mathbf{x}) = 1, \tag{8}$$

are both correct and observationally *equivalent* without further restrictions on ε and η; just define $\varepsilon \equiv y - \mu(\mathbf{x})$ and $\eta \equiv y/\mu(\mathbf{x})$ (assuming that $P[\mu(\mathbf{x}) > 0] = 1$). [...] (7) and (8) are simply different ways of stating that $E(y|\mathbf{x}) = \mu(\mathbf{x})$." (p. 938). PPML, as a Pseudo-Maximum-Likelihood estimator, only assumes the correct specification of the conditional expectation function, which is assumed the be the same in the additive and multiplicative case. Additional discussion of the use of additive vs. multiplicative error formulations can be found in Mullahy (1997) and Windmeijer and Santos Silva (1997).

π_i is an exporter fixed effect that accounts for the outward multilateral resistances and for sales/outputs, and χ_j is an importer fixed effect that accounts for expenditures and for the inward multilateral resistances.[10] To avoid perfect collinearity, we either have to drop one

[10] With panel data, the directional fixed effects should also be time-varying.

exporter and one importer fixed effect or one fixed effect and the constant. Our choice is to drop one importer fixed effect, χ_0, and the constant, implying that all other fixed effects are identified relative to χ_0. Further, note that solving the system (2)-(3) requires normalizing one of the multilateral resistances. By choice, we normalize the multilateral resistance that corresponds to the dropped importer fixed effect, $\widetilde{P}_0 = 1$. With the normalized $\widetilde{P}_0 = 1$, the theoretical interpretation of the importer fixed effect $\widetilde{\chi}_0$ is E_0, but since it is dropped, $\widetilde{\chi}_0 = 0$.[11] Then, the theoretical interpretation of all other fixed effects is relative to E_0.

Fally (2015) demonstrates that the PPML estimates of the fixed effects from gravity estimations are perfectly consistent with the structural gravity terms. (See his Proposition 1.) Taking into account the normalization that we just discussed, this implies that the OMRs and IMRs can be recovered from the fixed effects as follows:

$$\widetilde{\Pi_i^{1-\sigma}} = E_0 Y_i \exp\left(-\widetilde{\pi}_i\right), \tag{9}$$

and

$$\widetilde{P_j^{1-\sigma}} = \frac{E_j}{E_0} \exp\left(-\widetilde{\chi}_j\right), \tag{10}$$

where $\widetilde{\pi}_i$ and $\widetilde{\chi}_j$ are the estimated fixed effects from Equation (6), and Y_i, E_j and E_0 are data. It should be emphasized that the correct solution of the IMRs and OMRs does not depend on any statistical properties or necessary assumptions of the PPML estimator. It merely uses underlying theory to derive the relationship between the fixed effects and the IMRs and OMRs. Hence, as long as we have consistent estimates for trade costs, whether obtained with PPML, OLS, or Gamma PML, to name just some prominent examples, we will get the corresponding proper IMRs and OMRs due to the PPML properties. We capitalize on this property of PPML in the next section, where we also exploit the full structure of system (1)-(4) in order to develop our GEPPML procedure.

[11] We use a tilde ($\tilde{}$) to denote estimates. Following the literature, we reserve the hat-symbol ($\hat{}$) to later denote changes.

3 General Equilibrium Gravity Analysis with PPML

This section describes our simple 3-step procedure to obtain the general equilibrium effects of trade policy with the PPML estimator.

- **Step 1:** ***'Baseline' Scenario***. This step delivers the 'Baseline' estimates and 'Baseline' GE indexes and consists of two sub-steps:

  Step 1.a: ***Estimate 'Baseline' Gravity***. Use the PPML estimator to estimate gravity with exporter and importer fixed effects:

$$X_{ij} \quad = \quad \exp\left(\mathbf{T}_{ij}\boldsymbol{\beta} + \pi_i + \chi_j\right) \times \epsilon_{ij}. \tag{11}$$

  We chose PPML as our preferred estimator in this step for consistency with the rest of our procedure and due to its appealing properties for gravity estimations (see Santos Silva and Tenreyro, 2006, 2011).

  Importantly, we note that our procedure can readily accommodate three alternative and widely used approaches to treat bilateral trade costs and their elasticities in the existing literature. First, we emphasize that *any* estimator can be employed to obtain the estimates of the trade cost elasticities $\boldsymbol{\beta}$ in a preliminary step. For example, Head and Mayer (2014) argue that OLS and the Gamma PML estimators may dominate the performance of PPML under certain conditions. It is not our objective to compare the performance of different gravity estimators. However, we do note that our procedure can be implemented with estimates of the trade costs elasticities that are obtained with any estimator of choice. In fact, the $\boldsymbol{\beta}$'s can even be borrowed from other studies, which may not even use the same trade flows data, as is routinely done in the literature. In case the estimates of the trade cost elasticities are obtained externally or with another estimator than PPML, Step 1.a should be repeated with the external elasticity parameters or the obtained parameters from the estimator of your choice imposed as constraints in the PPML estimation (11):

$$X_{ij} = \exp\left(\mathbf{T}_{ij}\overline{\boldsymbol{\beta}} + \pi_i + \chi_j\right) \times \epsilon_{ij}, \tag{12}$$

where $\overline{\boldsymbol{\beta}}$ denotes the constrained set of trade cost coefficients. PPML will ensure that the estimates of the fixed effects adjust, so that the corresponding multilateral resistances are consistent with the chosen trade cost elasticities. In principle, we think that it is valuable to obtain trade costs elasticities with the same data that will be used for the counterfactual analysis. However, sometimes it is not possible to estimate certain parameters directly within the gravity framework. In that case, the method that we just described should be useful.[12]

Second, our procedure can also be applied when the whole trade cost vector is obtained externally, for example with the tetrads methods of Romalis (2007) or with any other ratio methods that are used in the literature. In case the trade cost matrix is obtained externally, Step 1.a should be repeated with the given trade cost vector of choice imposed as a constraint in the PPML estimation (11):

$$X_{ij} = \exp\left(\bar{\mathbf{T}}_{ij} + \pi_i + \chi_j\right) \times \epsilon_{ij}, \tag{13}$$

where $\bar{T}_{ij}$ denotes the constrained vector of trade costs. Once again, PPML will ensure that the estimates of the fixed effects adjust, so that the corresponding multilateral resistances are consistent with the chosen external vector of trade costs. A potential disadvantage of such a calibration procedure is that it essentially assumes rather than tests for causal relationships between trade costs and certain trade cost components

[12] For example, we believe that this alternative approach could be very valuable in a study of the effects of regional trade agreements (RTAs) but where, for some reason, only cross section data were available. It is well-known that, due to endogeneity, it is hard to obtain sound RTA estimates with cross section data, cf. Baier and Bergstrand (2007). However, one can borrow RTA estimates from panel studies that successfully account for RTA endogeneity, e.g. Baier and Bergstrand (2007) and Anderson and Yotov (2016), and simply impose them as constraints in this step.

and international trade. Next, we propose a hybrid procedure that overcomes this difficulty.

Third, our methods can be used to obtain trade costs from a hybrid "estibration" procedure, which enables us to *estimate* key elasticities of interest, and simultaneously to construct a vector of bilateral trade costs that matches the trade flows data perfectly, i.e. to *calibrate* trade costs. As in the previous two cases, this procedure can be implemented with an intermediate step that treats the error term from specification (11) as an accurately observed component of the vector of trade costs. The predicted and actual trade flow is:

$$X_{ij} \quad = \quad \exp\left(\widetilde{\mathbf{T}}_{ij} + \pi_i + \chi_j\right). \tag{14}$$

Here $\widetilde{\mathbf{T}}_{ij} = \mathbf{T}_{ij}\widetilde{\boldsymbol{\beta}} + \ln(\widetilde{\epsilon}_{ij})$, where $\mathbf{T}_{ij}$ is the vector of trade cost variables and $\widetilde{\boldsymbol{\beta}}$ are the corresponding trade cost elasticities from (11), and $\widetilde{\epsilon}_{ij} = X_{ij}/\widetilde{X}_{ij} = X_{ij}/\exp(\mathbf{T}_{ij}\widetilde{\boldsymbol{\beta}} + \widetilde{\pi}_i + \widetilde{\chi}_j)$ is defined as the ratio between actual and predicted trade from (11). Specification (14) no longer includes an error term because with the new definition of trade costs this equation is an identity.[13] In Section 4.2 we demonstrate that when trade costs are "estibrated", our procedure delivers results that are identical to those obtained with the 'exact hat' algebra methods of Dekle, Eaton and Kortum (2007, 2008). An important difference between the two methods is that the present procedure enables estimation of key trade policy variables of interest, e.g. RTAs, while at the same time it calibrates bilateral trade costs to match the trade flows data perfectly.

Finally, we note that Step 1.a, in its original version, as well as the "estibration" version of it can be used to generate a whole distribution of bootstrapped trade cost elasticity parameters that can be fed into the next steps in order to generate confidence intervals

[13]This can be seen by plugging in $\widetilde{T}_{ij}$ into (14): $X_{ij} = \exp(\widetilde{\mathbf{T}}_{ij} + \pi_i + \chi_j) = \exp(\widetilde{\mathbf{T}}_{ij})\exp(\pi_i)\exp(\chi_j) = \exp(\mathbf{T}_{ij}\widetilde{\boldsymbol{\beta}} + \ln(\widetilde{\epsilon}_{ij}))\exp(\pi_i)\exp(\chi_j) = \exp(\mathbf{T}_{ij}\widetilde{\boldsymbol{\beta}})\widetilde{\epsilon}_{ij}\exp(\pi_i)\exp(\chi_j) = \exp(\mathbf{T}_{ij}\widetilde{\boldsymbol{\beta}})\frac{X_{ij}}{\exp(\mathbf{T}_{ij}\widetilde{\boldsymbol{\beta}})\exp(\widetilde{\pi}_i)\exp(\widetilde{\chi}_j)}\exp(\pi_i)\exp(\chi_j)$, and hence, the equation holds without error term with $\widetilde{\pi}_i = \pi_i$ and $\widetilde{\chi}_j = \chi_j$.

for the GE indexes of interest, as is for example done by Anderson and Yotov (2016) and Larch and Wanner (2017).[14]

Step 1.b: ***Construct 'Baseline' GE Indexes***. Use the estimates of the fixed effects from (11) together with data on outputs and expenditures to construct the multilateral resistances according to (9)-(10), where, by construction, $Y_i = \sum_j X_{ij}$ and $E_j = \sum_i X_{ij}$. Construct any other baseline GE indexes of interest (e.g. predicted exports, $\sum_{j \neq i} \widetilde{X}_{ij}$, $\forall i$).

Note that in order to be able to perform counterfactual analysis, we need values for all inward and outward multilateral resistance terms, in addition to the inward multilateral resistance which is normalized. This is only possible if, after dropping one importer fixed effect and the constant, PPML does not drop any additional fixed effects or observations. If additional fixed effects are dropped, one may need to check and adjust the data in order to avoid the dropping of fixed effects by PPML. For example, one may drop countries with zero reported exports or imports to all trading partners.

- **Step 2:** ***'Conditional' Scenario.*** This step delivers the 'Conditional' gravity estimates and 'Conditional' GE indexes, which allow for changes in the IMRs and OMRs in response to changes in trade costs, but do not take output and expenditure changes into account. Again, this step consists of two sub-steps:

Step 2.a: ***Estimate 'Conditional' Gravity.*** Re-define the policy variable(s) of interest to reflect any desired trade policy changes and use PPML to estimate:

$$X_{ij} \quad = \quad \exp\left(\mathbf{T}_{ij}^{c}\widetilde{\boldsymbol{\beta}} + \pi_i^c + \chi_j^c\right) \times \epsilon_{ij}^c. \tag{15}$$

[14] Furthermore, in principle, our approach can be used to deliver standard errors for the indexes of interest directly from the estimates of the gravity fixed effects. However, as only recently the consistency of the model parameter estimates in nonlinear panel models with two types of fixed effects has been shown by Fernández-Val and Weidner (2016), we leave this potentially important analysis for future research.

Here $\mathbf{T}_{ij}^c$ is the vector of counterfactual trade policy covariates. For example, an indicator for Regional Trade Agreements (RTAs) can be amended to eliminate an existing agreement or to introduce a new one;[15] the tilde on $\boldsymbol{\beta}$ indicates the fact that the trade cost coefficients are constrained to the estimated values from the baseline specification (11); and the superscript c denotes counterfactual variables. Notice that the data remains the same in this counterfactual exercise: X_{ij} remains the same and thus so do Y_i and E_j. The experiment infers the fixed effects (multilateral resistances) that are consistent with the original data with the counterfactual trade costs $\mathbf{T}_{ij}^c$.

This step can be implemented directly in Stata (StataCorp LP, 2013) using version 2.2.2 (October 10th, 2015) or newer of 'ppml' command of Santos Silva and Tenreyro (2006) with the 'offset()' option to implement the counterfactual scenario as a constraint on the gravity trade costs, i.e.,

$$\texttt{ppml}\ X_{ij}\ \ \pi_i^c\ \ \chi_j^c\texttt{, noconst offset(}\mathbf{T}_{ij}^c\widetilde{\boldsymbol{\beta}}\texttt{).} \tag{16}$$

To obtain the latest version of the 'ppml' command just type 'ssc install ppml' in Stata. Appendix B includes a code that implements Steps 1 through 3 in Stata (StataCorp LP, 2013). The full Stata codes accompanying this paper are available upon request.

Step 2.b: ***Construct 'Conditional' GE Indexes***. Repeat Step 1.b with the new fixed effects estimates from (15) and the original data on outputs and expenditures to construct the 'Conditional' GE (the Modular Trade Impact of Head and Mayer, 2014) values of the multilateral resistances and construct any other GE indexes of interest. The differences, in percentage, between the baseline indexes from Step 1.b and the counterfactual indexes from this step measure the 'Conditional' GE effects of the simulated trade policy. Specifically, the percentage change in welfare in the

[15] Our methods will also hold if we adjust estimates in the vector of the trade cost elasticities, $\boldsymbol{\beta}$.

'Conditional' GE scenario can be calculated by the change in real GDP, i.e.,[16]

$$\widehat{W}_i = \frac{Y_i^c/\widetilde{P}_i^c}{Y_i/\widetilde{P}_i} = \frac{\widetilde{P}_i}{\widetilde{P}_i^c},\ \forall i, \tag{17}$$

where moving from the middle to the rightmost equality recognizes that output is kept exogenous in the 'Conditional' scenario, i.e. $Y_i^c = Y_i$.

Note that we obtain power transforms of the inward multilateral resistances according to Equation (10). Therefore, to construct real GDP, we use a standard value for the elasticity of substitution $\sigma = 7$. In principle, σ can also be estimated directly from an empirical gravity model that includes as a covariate any direct price shifter, e.g. tariff. See for an overview of varies ways to obtain estimates for the elasticity of substitution Head and Mayer (2014).

- **Step 3:** ***'Full Endowment' Scenario.*** This step delivers the 'Full Endowment' gravity estimates and 'Full Endowment' GE indexes, which in addition to changes in the IMRs and OMRs capture changes in output and expenditure. Also Step 3 consists of two sub-steps:

  Step 3.a: ***Estimate 'Full Endowment' Gravity.*** Allow for endogenous response in the value of outputs/incomes and expenditures, which are given by $Y_i^c = (p_i^c/p_i)\, Y_i$ and $E_i^c = (p_i^c/p_i)\, E_i$ in an endowment economy where trade imbalance ratios $\phi_i = E_i/Y_i$ are assumed to stay constant in the counterfactual for each country i (allowing for balanced trade as a special case). The endogenous changes in output/income and expenditure will trigger additional changes in the multilateral resistance (MR) terms and so forth. As the PPML estimator with the appropriate fixed effects ensures that the sum of fitted values of GDPs and expenditures is equal to the sum of observed values of GDPs and expenditures, changes in output/income and expenditure cannot

[16]Note that due to our normalization of $\widetilde{P}_0 = 1$, welfare changes in the 'Conditional' scenario are relative to reference country 0.

be directly calculated in one step with PPML. Therefore, we use the structural gravity Equation (1) to translate the changes in output and expenditure, triggered by the changes in factory-gate prices, into changes in trade flows:

$$\widetilde{X}_{ij}^{c} = \frac{\left(\widetilde{t_{ij}^{1-\sigma}}\right)^{c}}{\widetilde{t_{ij}^{1-\sigma}}} \frac{\widetilde{Y}_{i}^{c}\widetilde{E}_{j}^{c}}{Y_{i}E_{j}} \frac{\widetilde{\Pi_{i}^{1-\sigma}}\widetilde{P_{j}^{1-\sigma}}}{\left(\widetilde{\Pi_{i}^{1-\sigma}}\right)^{c}\left(\widetilde{P_{j}^{1-\sigma}}\right)^{c}} X_{ij}, \tag{18}$$

where $\widetilde{t_{ij}^{1-\sigma}} = \exp\left(\mathbf{T}_{ij}\widetilde{\boldsymbol{\beta}}\right)$ and $\left(\widetilde{t_{ij}^{1-\sigma}}\right)^{c} = \exp\left(\mathbf{T}_{ij}^{c}\widetilde{\boldsymbol{\beta}}\right)$. Note that all ratios on the right-hand side of (18) can be expressed only in terms of the estimates of the exporter and of the importer fixed effects. Using Equations (9) and (10), new multilateral resistances are obtained as functions of the estimates of the fixed effects and of the new values of income and expenditure:

$$\left(\widetilde{\Pi_{i}^{1-\sigma}}\right)^{c} = E_{0}^{c}\widetilde{Y}_{i}^{c}\exp\left(-\widetilde{\pi}_{i}^{c}\right), \tag{19}$$

and

$$\left(\widetilde{P_{j}^{1-\sigma}}\right)^{c} = \frac{\widetilde{E}_{j}^{c}}{E_{0}^{c}}\exp\left(-\widetilde{\chi}_{j}^{c}\right). \tag{20}$$

In turn, the new values for outputs and expenditures, $\widetilde{Y}_{i}^{c}$ and $\widetilde{E}_{j}^{c}$, are obtained by using the market clearing conditions $p_i = \left(\frac{Y_i}{Y}\right)^{\frac{1}{1-\sigma}} \frac{1}{\gamma_i \Pi_i}$ to translate the 'Conditional' GE effects on the MR terms into 'first-order' changes in factory-gate prices, i.e.

$$\widetilde{p_{i}^{c}/p_{i}} = \left[\exp\left(\widetilde{\pi}_{i}^{c}\right)/\exp\left(\widetilde{\pi}_{i}\right)\right]^{\frac{1}{1-\sigma}}, \tag{21}$$

where, as imposed in Step 1, the vector of prices $\{p_i^c\}$ is normalized by $P_0 = \sum_i \left(\gamma_i p_i t_{i0}\right)^{1-\sigma} = 1$. Note that the changes in trade implied by Equation (18) are not the 'Full Endowment' GE changes. The reason is that they only reflect the 'Conditional' OMR changes and do not allow for immediate changes in the value of outputs. This is why we label these initial changes in the factory-gate prices and in trade '*first-*

order'. Thus, in effect, the methods that we represent here are an interactive procedure that corresponds to the 'exact hat' procedures from Dekle, Eaton and Kortum (2007, 2008). When trade costs are 'estibrated', as described earlier in this section, our procedure and the methods from Dekle, Eaton and Kortum (2007, 2008) deliver identical results. We demonstrate this in Section 4.2 below.

Repeat Step 2.a with the new values for trade. The idea is that, using the new values of trade, the PPML estimator will translate the initial response of factory-gate prices into changes in the gravity fixed effects, which (in combination with the new values for income $\widetilde{Y}_i^c = \sum_j \widetilde{X}_{ij}^c$ and expenditures $\widetilde{E}_j^c = \sum_i \widetilde{X}_{ij}^c$) can be used to obtain additional 'second-order' responses in the MR terms. Repeat Step 3.a to obtain a new set of factory-gate prices and new values of trade, income and expenditures. Iterate until convergence, e.g. until the change between two subsequent iterations in each of the factory-gate prices is smaller than a pre-defined tolerance criterion.

Step 3.b: ***Construct 'Full Endowment' GE Indexes***. Construct 'Full Endowment' GE indexes of interest following the procedures from Step 1.b. The differences, in percentage, between the baseline indexes from Step 1.b and the counterfactual indexes from this step measure the 'Full Endowment' GE effects of the simulated trade policy. The percentage change in welfare in the 'Full Endowment' GE scenario can again be calculated by the change in real GDP, i.e.,

$$\widehat{W}_i = \frac{\widetilde{Y}_i^c / \widetilde{P}_i^c}{Y_i / \widetilde{P}_i}, \ \forall i. \tag{22}$$

Note that with balanced trade or constant shares of trade imbalances, the change in output and expenditure are identical for each country. Hence, real GDP changes correspond to changes in real expenditures. Further, Arkolakis, Costinot and Rodríguez-Clare (2012) demonstrate that the welfare/real consumption gains from trade liberalization obtained from a wide class of trade models with alternative microfoundations can all be expressed as a combination of two sufficient statistics including intra-national trade as share of total expenditures (X_{ii}/E_i) and the trade elasticity of substitution $(1 - \sigma)$. This holds for our framework.

These three steps can be performed with any statistic/econometrics software that is able to estimate a constrained Poisson model and is capable of handling loops. Specifically, no non-linear equation solver is necessary. Hence, it can be easily applied by anyone working empirically.[17]

Our procedures closely resemble the 'exact hat' algebra procedures from Dekle, Eaton and Kortum (2007, 2008). They differ quantitatively from the usual practice in using the predicted value of bilateral trade instead of the observed value of trade. But, as demonstrated earlier, the latter can be accommodated by using calibrated or "estibrated" trade costs. Otherwise, as is well understood now, in the one good case the Armington CES endowments model is an equivalent representation of the structural gravity model. The CES parameter $1 - \sigma$ is alternatively interpreted as a Frèchet distribution parameter and the sales variable $Y_i = p_i Q_i$ is interpreted as the wage bill $w_i L_i$.

4 A World Without Borders

In this section, we focus on a hypothetical scenario that removes all international borders to trade in manufactures for 40 countries and a rest-of-world aggregate over the period 1990-2002. Our experiment of removing international borders while preserving the effects of geography can be interpreted as a quantification of the effects of an effective multilateral trade facilitation exercise, thus, complementing the widely used counterfactual analysis of reversal to autarky, cf. Costinot and Rodríguez-Clare (2014).[18]

[17] In Appendix A we discuss possible extensions of our methods beyond a one sector economy.

[18] In analysis that is available by request we also perform a battery of robustness experiments with various alternative scenarios and specifications including decreasing and increasing distance, removing and introduc-

The data set that we employ here is a subsample of the data from Anderson and Yotov (2016), which covers total manufacturing trade, including intra-national trade for 40 countries and a rest of the world aggregate over the period 1990-2002. We focus on the year 2002 and we refer the reader to Anderson and Yotov (2016) for further details on the dataset. We present two sets of analysis based on the same counterfactual scenario. First, we use estimated trade costs as the base for the experiment. Then, we employ a vector of "estibrated" trade costs, which treat the gravity error term as a trade cost component and, therefore, match the trade flows data perfectly.

4.1 A Counterfactual Analysis with *Estimated* Trade Costs

We start with a counterfactual analysis that is based on a vector of estimated bilateral trade costs from a simple empirical gravity specification:

$$X_{ij} = \exp\left(\beta_1 \ln DIST_{ij} + \beta_2 CNTG_{ij} + \beta_3 BRDR_{ij} + \pi_i + \chi_j\right) \times \epsilon_{ij}, \tag{23}$$

where all bilateral trade costs are approximated by the logarithm of bilateral distance, $\ln DIST_{ij}$, an indicator variable that takes a value of one when trading partners i and j are contiguous, $CNTG_{ij}$, and an indicator variable for international borders, $BRDR_{ij}$, which takes a value of one for international trade and it is equal to zero otherwise. Specification (23) is consistent with structural gravity due to the presence of the exporter and importer fixed effects, which account for the multilateral resistances as well as for outputs and expenditures. Note that despite its simplicity, Equation (23) represents a comprehensive specification that decomposes the effects of geography, as captured by distance and contiguity, vs. the effects of all other observable and unobservable barriers to trade, which are

ing RTAs, removing and introducing contiguous borders, changing the values for the trade cost elasticities, and using alternative data samples including cross-section and panel data. All these experiments confirm the robustness of our methods and the empirical equivalence between the results from the GEPPML procedure that we propose here and those from a standard procedure that requires setting and solving the structural gravity system explicitly. The Stata codes (implemented in Stata, StataCorp LP, 2013) and the Matlab codes (implemented in Matlab, Mathworks, 2013) are available upon request.

conveniently captured by the exogenous, by construction, indicator variable for international borders. In that sense, our analysis based on (23) can be viewed as a quantification of the effects of an effective multilateral trade facilitation.

Step 1.a delivers estimates of the effects of distance, contiguity and international borders:

$$X_{ij} = \exp(\underset{(0.052)}{-0.948} \ln DIST_{ij} + \underset{(0.102)}{0.478} CNTG_{ij} - \underset{(0.122)}{1.555} BRDR_{ij} + \widetilde{\pi}_i + \widetilde{\chi}_j) \times \widetilde{\epsilon}_{ij}. \quad (24)$$

The estimates of the standard gravity variables are in accordance with prior expectations. A negative and highly statistically significant estimate of the effect of distance $\widetilde{\beta}_1 = -0.948$ (std.err. 0.052) does not differ significantly from the conventional estimate of -1. There is a positive and highly significant effect of contiguity $\widetilde{\beta}_2 = 0.478$ (std.err. 0.102). Both estimates are readily comparable with existing indexes from the literature. See Head and Mayer (2014). This establishes the representativeness of our sample. In addition, our estimates suggest that, all else equal, international borders decrease trade by an average of 79 percent (std.err. 2.575), calculated as $\left(\exp\left[\widetilde{\beta}_3\right] - 1\right) \times 100$ with standard errors obtained with the Delta method. The estimates from Equation (24) can be used to construct all baseline indexes of interest, as specified in Step 1.b of our procedure. Their values are suppressed for expositional ease.

Next, we follow Step 2.a to obtain 'Conditional' GE estimates that correspond to the removal of international borders:

$$X_{ij} = \exp\left(-0.948 \ln DIST_{ij} + 0.478 CNTG_{ij} + \widetilde{\pi}_i^c + \widetilde{\chi}_j^c\right) \times \widetilde{\epsilon}_{ij}^c. \quad (25)$$

Here, we have constrained the estimates on the trade cost covariates to their baseline values and we have removed the international border covariate completely, which is equivalent to keeping it with all values of the international border dummy $BRDR_{ij}$ set to zero. We use the estimates of the fixed effects and of the coefficients on the trade cost variables to construct multilateral resistances, total exports, and real consumption for each of the countries in our sample as described in Step 2.b. Finally, we follow Step 3 to obtain estimates and GE indexes of the 'Full Endowment' GE effects of the removal of international borders. In order to check the validity of our approach, we obtain the same indexes by solving the non-linear gravity system in Matlab and compare the results graphically. The corresponding figures are in Appendix C.

The general equilibrium estimates are presented in Table 1. We first focus on the results for the 'Conditional' general equilibrium. These results can be seen as quantifying the full trade cost changes, i.e. direct trade cost changes and indirect trade cost changes (via the inward and outward multilateral resistances), but holding expenditures and sales constant. Concerning exports, we find that all countries see an increase. However, there is a substantial heterogeneity ranging from 7 percent for Bulgaria to 151 percent for the US. This heterogeneity is not revealed when merely looking at the point estimates, which suggested an average increase of trade flows of 79 percent, as discussed above.

More interestingly, these trade effects generate quite substantial differences in real GDP (our measure of welfare). Our results suggest that abolishing international borders leads to welfare changes between about -7 and 14 percent relative to our reference country Germany, where real GDP changes in the 'Conditional' GE equilibrium are zero by construction. Note that the exact magnitudes depend on the size of the trade elasticity, which we set to $1-\sigma = 1-7 = -6$. We next disentangle the effects on consumers and producers using the inward and outward multilateral resistances, respectively. IMRs for most countries relative to Germany fall, implying a decrease in consumer prices. However, for some countries we see an increase in consumer prices (relative to Germany), such as for the US. Producer prices fall for all countries, and there is less variability in the results as compared to trade flows, ranging from -5 percent for the US to -20 percent for Bolivia.

Next, we compare the 'Conditional' GE effects with the 'Full Endowment' effects, that in addition to the full trade cost changes also capture changes in expenditures and sales resulting from the removal of all international borders. The trade effects are magnified by 24 to 33 percentage points. Similarly, real GDP effects increase substantially too. Note that when taking into account the changes in expenditures and sales, all countries see positive welfare gains. The results imply that abolishing international borders leads to welfare gains between about 4.8 percent and 40.3 percent. Overall, our findings indicate that a complete removal of international borders would benefit the most developed and large nations less than the less developed and smaller economies in our sample. The country that would gain the least is the United States, closely followed by Japan (5.6 percent). China, Korea and Germany all would register gains from the complete removal of international borders of less than 15 percent. Great Britain is sixth form the bottom in our list with a gain of 15.5 percent. On the other side of the spectrum we find smaller and less developed economies. The biggest winners from the complete removal of international borders include some Latin American economies. Bolivia would enjoy the largest increase in real GDP (40.3 percent). Uruguay, Ecuador, Mexico, Colombia are also in the top-10 countries according to this criteria with gains of more than 30 percent. Other big winners include some European economies, e.g. Iceland, Bulgaria, and Norway, as well Canada, Tunisia, and Morocco.

Also in the 'Full Endowment' GE scenario all producers gain by falling OMRs and increasing producer prices. The increase in producer prices range from 6 percent for the US to 24 percent for Bolivia. Consumer prices for most countries fall, however, in some countries consumer prices increase (relative to Germany). Comparing the magnitudes of the IMRs and OMRs, we find that the OMRs are for many countries around double the size, implying that two thirds of the gains from removing the border would fall on produces, while the remaining third would fall on the consumers.

The result that more developed countries will gain less from a potential removal of international borders quantifies the familiar undergraduate textbook intuition that the smaller of two countries gains more moving from autarky to free trade, and the newer intuition from Arkolakis, Costinot and Rodríguez-Clare (2012) that larger countries with a naturally larger home market share gain less. The quantification of removing borders only includes, however, the important modifying factor of bilateral distance penalties that differ between large and small economies. For example, Europe and North America are relatively compact groups of large economies that might be expected to gain more from a given drop in border barriers. The modifying effect of distance especially shows up in relatively large gains for small European and Latin American economies.

Note that the heterogeneity in our welfare effects is driven exclusively by general equilibrium forces, since we obtain and use a single/common estimate of the effects of international borders on international trade. Decomposing the partial equilibrium effects of international borders on trade in developed versus developing countries is beyond the scope of this paper and, arguably, our sample coverage is not well suited for this task. However, combined with the findings form other studies, e.g. Waugh (2010), that developing countries are subject to disproportionately large trade costs, our results suggest that the gap between the potential effects of multilateral/global trade liberalization would be even wider.

4.2 A Counterfactual Analysis with *"Estibrated"* Trade Costs

This section demonstrates that the GEPPML procedure can deliver results that are identical to those that are obtained with the non-linear solvers based on calibrated trade costs and also identical to the 'exact hat' algebra methods of Dekle, Eaton and Kortum (2007, 2008). Specifically, this can be achieved when we use an "estibrated" trade cost vector that includes the estimated trade costs components as well as the gravity error term.[19]

As discussed in Section 3, the analysis with "estibrated" trade costs introduces an intermediate estimation at Step 1. As before, we start by estimating the initial gravity specification:

$$X_{ij} = \exp(\underset{(0.052)}{-0.948} \ln DIST_{ij} + \underset{(0.102)}{0.478} CNTG_{ij} - \underset{(0.122)}{1.555} BRDR_{ij} + \widetilde{\pi}_i + \widetilde{\chi}_j) \times \widetilde{\epsilon}_{ij}. \qquad (26)$$

[19]Appendix D includes the Dekle, Eaton and Kortum (2007, 2008) system in changes, which we implement in Matlab. Note that the Dekle, Eaton and Kortum (2007, 2008) procedure delivers only changes that correspond to the 'Full Endowment' scenario, while our approach can also be used to calculate the 'Conditional' GE effects.

Then, we construct the "estibrated" trade cost vector:

$$\widetilde{\mathbf{T}}_{\mathbf{ij}} = \mathbf{T}_{ij}\widetilde{\boldsymbol{\beta}} + \ln\left(\widetilde{\epsilon}_{ij}\right), \tag{27}$$

where $\mathbf{T}_{ij}$ is the vector of trade cost variables and $\widetilde{\boldsymbol{\beta}}$ are the corresponding trade cost elasticities from (11), and $\widetilde{\epsilon}_{ij} = X_{ij}/\widetilde{X}_{ij}$ is defined as the ratio between actual and predicted trade from (26). We use the new trade cost vector, properly adjusted for the removal of borders, to estimate the 'conditional' gravity specification:

$$X_{ij} \quad = \quad \exp\left(\widetilde{\mathbf{T}}_{ij}^{c} + \pi_{i}^{c} + \chi_{j}^{c}\right), \tag{28}$$

with $\widetilde{\mathbf{T}}_{ij}^{c} = \mathbf{T}_{ij}^{c}\widetilde{\boldsymbol{\beta}} + \ln\left(\widetilde{\epsilon}_{ij}\right)$ to obtain the corresponding 'conditional' GE indexes. Finally, we follow Step 3 with the "estibrated" conditional trade cost vector to obtain estimates and GE indexes of the 'Full Endowment' GE effects of the removal of international borders.

Results based on the "estibrated" trade costs are presented in Table 2. We first look at the effects for the 'Conditional' GE scenario. Again, exports for all countries increase if international borders are removed. And, as with estimated trade costs, we see quite substantial variation of the effects on trade across countries. Compared to the results with estimated trade costs, we see quite substantial increases for many countries, such as e.g. Ecuador, Columbia, and Bolivia, while for others, such as e.g. the Netherlands, Great Britain, and Belgium and Luxembourg, we see smaller trade effects, even though less substantial. Real GDP effects relative to Germany vary now a bit more, with some more countries being less well off than Germany (such as e.g. Argentina and Brazil). The decomposition on consumers and producers delivers a quite similar picture: producers gain in all countries, and the gains are more substantial than the ones for consumers.

Next, turn to the results for the 'Full Endowment' GE scenario. As with estimated trade costs, the changes in exports are magnified between 27 and 38 percentage points. Comparison between the real GDP effects with the estimated and the "estibrated" trade costs reveal that the effects of the border removal based on the estimated trade cost vector are lower for some countries (e.g. Netherlands and Ireland) and higher for others (e.g. Bolivia and Columbia). The natural explanation for this result is that when the vector of trade costs itself is lower for some countries, i.e. when trade costs are smaller, the effect of the border removal is larger. Once again, output prices in all countries increase, while consumer prices decrease in some countries and increase in others. Also, similar to our previous results, we find that the effects on producers are stronger than on consumers.

Overall, our welfare gains from the removal of international borders are readily comparable in terms of economic magnitude to those from Costinot and Rodríguez-Clare (2014), who measure a move from autarky to current trade (liberalization) levels. For example, the welfare gains in Costinot and Rodríguez-Clare (2014) for US (from a scenario with perfect competition with multiple sectors, and intermediates) are calculated to be 8.3 percent. Our values of potential gains from the removal of borders is very close at 5.2 percent. For Germany, Costinot and Rodríguez-Clare (2014) obtain a welfare increase of 21.3 percent, while we calculate an increase 19.4 percent. This similarity holds more or less for all countries that enter our sample and the sample of Costinot and Rodríguez-Clare (2014) and it suggests that at this stage we have enjoyed at most half of the possible gains from trade and trade liberalization and that there is significant scope for further gains from trade in the future. As noted earlier, we may therefore conclude that the world has enjoyed *at most* half of the gains from trade because the other scenarios considered by Costinot and Rodríguez-Clare (2014) generate smaller gains.[20]

While the qualitative pattern in our results is quite similar between the scenarios with estimated and "estibrated" trade costs, we also see some substantial quantitative differences for some countries. The implication of this result is the error term in cross section gravity estimation may indeed carry systematic information about trade costs. We expect that the

[20] For example, in a one sector world and perfect competition Costinot and Rodríguez-Clare (2014) obtain a value of 1.8 percent for the US and 4.5 percent for Germany. With multiple sectors, but not allowing for intermediates, the values are 4.4 percent and 12.7 percent for US and Germany, respectively.

differences between the estimated and estibrated scenarios will be significantly smaller in a panel setting, where all time-invariant bilateral trade costs are controlled for by pair fixed effects. However, in any case, we recommend that researchers and policy analysts should experiment with both the estimated and the "estibrated" trade costs.

4.3 On the Effects of the Border Between the US and Canada

We conclude our analysis with an investigation of the effects of the border between Canada and US, which has has spurred a great deal of interest in the trade literature (see for example McCallum, 1995; Anderson and van Wincoop, 2003). We view this as a valuable experiment for two reasons. First, from a methodological perspective, it will enable us to demonstrate how our estimation methods can be extended to identify the effects of a pair-specific international border. This is important since borders in the world can be quite heterogeneous across country pairs due to bilateral integration efforts, bilateral conflict, etc. Second, from a policy perspective, we use our method to simulate the impact of an asymmetric border removal in order to emphasize the distributional implications of trade policy and also to demonstrate how a mercantilist trade policy may benefit certain groups at the expense of others, while also hurting aggregate welfare.

First, in order to allow for a differential effect of the international border between the US and Canada, we split our border dummy into a dummy for the international border between the US and Canada ($BRDR\_USACAN_{ij}$), and for the rest of the world ($BRDR_{ij}$). As before, we start by estimating the initial gravity specification:

$$\begin{aligned} X_{ij} &= \exp(\underset{(0.054)}{-0.945} \ln DIST_{ij} + \underset{(0.106)}{0.471} CNTG_{ij} - \underset{(0.126)}{1.561} BRDR_{ij} \\ &\quad \underset{(0.156)}{-1.490} BRDR\_USACAN_{ij} + \widetilde{\pi}_i + \widetilde{\chi}_j) \times \widetilde{\epsilon}_{ij}, \end{aligned} \tag{29}$$

which shows that the partial effect of removing the international border between the US and Canada is not significantly different form the average (-77.5 percent with std.err. 3.508 for

$BRDR\_USACAN$ versus -79.0 percent wit std.err. 2.634 for $BRDR$).

Next, we construct the "estibrated" trade cost vector, $\widetilde{\mathbf{T}}_{\mathbf{ij}} = \mathbf{T}_{ij}\widetilde{\boldsymbol{\beta}} + \ln(\widetilde{\epsilon}_{ij})$, where $\mathbf{T}_{ij}$ is as before the vector of trade cost variables and $\widetilde{\boldsymbol{\beta}}$ are the corresponding trade cost elasticities from (29), and $\widetilde{\epsilon}_{ij} = X_{ij}/\widetilde{X}_{ij}$ is again defined as the ratio between actual and predicted trade from (29). We use the new trade cost vector, setting all values of $BRDR\_USACAN$ to zero, i.e. removing it as a regressor, to estimate the 'conditional' gravity specification:

$$X_{ij} = \exp\left(\widetilde{\mathbf{T}}^{c}_{ij} + \pi^{c}_{i} + \chi^{c}_{j}\right), \tag{30}$$

with $\widetilde{\mathbf{T}}^{c}_{ij} = \mathbf{T}^{c}_{ij}\widetilde{\boldsymbol{\beta}} + \ln(\widetilde{\epsilon}_{ij})$ to again obtain the corresponding 'conditional' GE indexes. As before, the final step is Step 3 with the "estibrated" conditional trade cost vector to obtain estimates and GE indexes of the 'Full Endowment' GE effects of the removal of international borders.

Results for the 'Full Endowment' scenario based on the "estibrated" trade costs are presented in Table 3, columns (2)-(6). We see that exports increase most strongly for Canada, 52 percent, while total exports of the US increase by 19 percent. These findings are in line with the intuition that smaller countries gain more from international trade than larger ones. These results are also well in line with the findings of Anderson and van Wincoop (2003) of an increase of trade between 20 to 50 percent. For most of the other countries we see slight negative effects on total exports, with some exceptions such as Spain, Hungary, Morocco, and Tunisia.

Turning to the effects on real GDP (our measure of welfare), we find that Canada will enjoy the largest increase in welfare, of 34 percent, while US welfare only increases modestly by 0.5 percent. All other countries see slight negative effects ranging from -0.5 percent for Mexico to -0.01 percent for Rumania, Morocco, and Tunisia. The gains for Canada are shared between producers and consumers, as IMRs (consumer prices) decrease and producer prices increase. For the US, we see that only producers gain by increasing prices, while consumers face higher prices. For the other countries, we mostly find increases in consumer and decreases in producer prices, explaining the negative welfare effects.

So far, we considered a symmetric abolishment of the border between the US and Canada. However, very often, policy makers adopt a mercantilist view and pursue asymmetric trade liberalization in favor of exports form their country. We use our setup to simulate such a scenario by only removing international border for exports of Canada to the US (i.e. imports from the US of goods from Canada). Our findings are reported in Table 3, columns (7)-(11). Several important results stand out. First, we see that the overall welfare effect on Canada in the asymmetric trade liberalization scenario is slashed by more than half as compared to the corresponding index when borders were removed reciprocally. Second, we see that the effects on Canadian producers are a bit stronger in the asymmetric border removal scenario. However, the difference with the effects in the symmetric scenario is very small (-17.29 vs. -16.74, respectively). Third, and most important, our results reveal a very significant change in the effects on Canadian consumers. Specifically, the difference in consumer prices between the two scenarios is 16 percentage points (from a fall of -13 percent in the symmetric trade liberalization to 3 percent in the asymmetric scenario). The explanation for this result is twofold: consumer prices fell a lot in the symmetric trade liberalization scenario due to imports from the efficient US producers, at the same time, faced with better opportunities to export in the asymmetric scenario, Canadian producers find it optimal to increase their prices for domestic sales. Finally, and as expected, we see the opposite results in US, where consumers enjoy a slight decrease in prices due to the surge of Canadian exports, while US producers suffer lower producer prices due to increase competition. In sum, the results from this scenario represent a classic example of how, by serving a given group (e.g. by protecting producers), policy makers may hurt overall welfare in the economy.[21]

[21] Results based on estimated instead of "estibrated" trade costs show qualitatively the same pattern, and quantitatively effects for Canada become a bit smaller, while the ones for the US become a bit larger. These results are presented in Table A1 in Appendix E.

5 Conclusions

Structural gravity models are now widely used to evaluate trade and other policies related to international trade flows in the academic literature (see for an overview Head and Mayer, 2014). While their merits are by now well understood (see for a discussion Costinot and Rodríguez-Clare, 2014), the widespread applications of these methods by more applied analysts and policymakers is still lagging behind. One of the main reasons for this sluggish adoption of these methods may well be that they require the use of non-linear solvers, which are not available or hard to use in standard applied econometrics software.

We therefore develop a simple procedure to perform structural gravity equation estimation, including the performance of counterfactual analysis. Our development rests on the shoulders of the theoretical developments of Anderson (1979) and Anderson and van Wincoop (2003) and the suggested estimation of structural gravity models by Santos Silva and Tenreyro (2006) and the investigated properties of this estimator by Fally (2015). Specifically, we exploit the combined properties of the theory and the properties of the suggested Poisson Pseudo-Maximum-Likelihood estimator to develop an approach that allows us to calculate conditional and full general equilibrium responses to changes in trade costs directly in any statistical software package capable of estimating constrained Poisson models and handling loops, labeled *GEPPML*. We also show that besides estimating trade costs, we can use a hybrid procedure that combines the estimation and predictive properties of the gravity model with a calibration approach that fits trade flows perfectly. We show that such an approach leads to identical results as the approach of Dekle, Eaton and Kortum (2007, 2008). We also compare these results from our GEPPML procedure with ones obtained by solving the non-linear equation system, leading to identical results. Additionally, we demonstrate how our framework can be extended beyond the endowment economy.

We apply our suggested GEPPML procedure to a hypothetical scenario that removes all international borders to trade in manufactures for 40 countries and a rest-of-world aggregate over the period 1990-2002. Our results suggest that abolishing international borders leads to welfare gains between about 5 and 40 percent when accounting for changes in multilateral resistance terms and general equilibrium effects via changes in output and expenditure. Additionally, we investigate the removal of the country-pair international border between the US and Canada, showing the potential large gains for Canada shared between consumers and producers, while we only find modest gains for the US accruing only to the producers. Finally, we also demonstrate that asymmetric trade liberalization may lead to small gains for the intended beneficiary at the expense of large losses for other groups and for national welfare.

References

Allen, Treb, Costas Arkolakis, and Yuta Takahashi. 2014. "Universal Gravity." unpublished manuscript, available for download at `http://www.econ.yale.edu/~ka265/ research.html`.

Anderson, James E. 1979. "A Theoretical Foundation for the Gravity Equation." *American Economic Review*, 69(1): 106–116.

Anderson, James E. 2011. "The Gravity Model." *Annual Review of Economics*, 3: 133–160.

Anderson, James E., and Eric van Wincoop. 2003. "Gravity with Gravitas: A Solution to the Border Puzzle." *American Economic Review*, 93(1): 170–192.

Anderson, James E., and Yoto V. Yotov. 2010. "The Changing Incidence of Geography." *American Economic Review*, 100(5): 2157–2186.

Anderson, James E., and Yoto V. Yotov. 2016. "Terms of Trade and Global Efficiency Effects of Free Trade Agreements, 1990-2002." *Journal of International Economics*, 99(C): 279–298.

Anderson, James E., Mario Larch, and Yoto V. Yotov. 2015. "Growth and Trade with Frictions: A Structural Estimation Framework." *NBER Working Paper No. 21377.*

Arkolakis, Costas, Arnaud Costinot, and Andrés Rodríguez-Clare. 2012. "New Trade Models, Same Old Gains?" *American Economic Review*, 102(1): 94–130.

Armington, P.S. 1969. "A Theory of Demand for Products Distinguished by Place of Production." *IMF Staff Papers*, 16: 159–176.

Baier, Scott L., and Jeffrey H. Bergstrand. 2007. "Do Free Trade Agreements Actually Increase Members' International Trade?" *Journal of International Economics*, 71(1): 72–95.

Balistreri, Edward J., and Russell H. Hillberry. 2005. "Estibration: An Illustration of Structural Estimation As Calibration." unpublished manuscript, available for download at https://inside.mines.edu/~ebalistr/Papers/estibration.pdf.

Caliendo, Lorenzo, and Fernando Parro. 2015. "Estimates of the Trade and Welfare Effects of NAFTA." *Review of Economic Studies*, 82(1): 1–44.

Costinot, Arnaud, and Andrés Rodríguez-Clare. 2014. "Trade Theory with Numbers: Quantifying the Consequences of Globalization." Chapter 4 in the Handbook of International Economics Vol. 4, eds. Gita Gopinath, Elhanan Helpman, and Kenneth S. Rogoff, Elsevier Ltd., Oxford, 197–261.

Dekle, Robert, Jonathan Eaton, and Samuel Kortum. 2007. "Unbalanced Trade." *American Economic Review: Papers and Proceedings*, 97(2): 351–355.

Dekle, Robert, Jonathan Eaton, and Samuel Kortum. 2008. "Global Rebalancing with Gravity: Measuring the Burden of Adjustment." *IMF Staff Papers*, 55(3): 511–540.

Eaton, Jonathan, and Samuel Kortum. 2002. "Technology, Geography and Trade." *Econometrica*, 70(5): 1741–1779.

Egger, Peter, Mario Larch, Kevin E. Staub, and Rainer Winkelmann. 2011. "The Trade Effects of Endogenous Preferential Trade Agreements." *American Economic Journal: Economic Policy*, 3(3): 113–143.

Fally, Thibault. 2015. "Structural Gravity and Fixed Effects." *Journal of International Economics*, 97(1): 76–85.

Feenstra, R.C. 2004. *Advanced International Trade: Theory and Evidence.* Princeton, New Jersey:Princeton University Press.

Fernández-Val, Iván, and Martin Weidner. 2016. "Individual and Time Effects in Nonlinear Panel Models with Large N, T." *Journal of Econometrics*, 192(1): 291–312.

Head, Keith, and Thierry Mayer. 2014. "Gravity Equations: Workhorse, Toolkit, and Cookbook." Chapter 3 in the Handbook of International Economics Vol. 4, eds. Gita Gopinath, Elhanan Helpman, and Kenneth S. Rogoff, Elsevier Ltd., Oxford, 131–195.

Hillberry, Russell H., Michael A. Anderson, Edward J. Balistreri, and Alan K. Fox. 2005. "Taste Parameters as Model Residuals: Assessing the "Fit" of an Armington Trade Model." *Review of International Economics*, 13(5): 973–984.

Larch, Mario, and Joschka Wanner. 2017. "Carbon Tariffs: An Analysis of the Trade, Welfare, and Emission Effects." *Journal of International Economics*, 109: 195–213.

Mathworks. 2013. "Matlab: Release 2013b." 3 Apple Hill Drive, Natick, MA 01760-2098, United States, http://www.mathworks.com/.

McCallum, John. 1995. "National Borders Matter." *American Economic Review*, 85(3): 615–623.

Mullahy, John. 1997. "Instrumental-Variable Estimation of Count Data Models: Applications to Models of Cigarette Smoking Behavior." *Review of Economics and Statistics*, 79(4): 586–593.

Romalis, John. 2007. "NAFTA's and CUSTFA's Impact on International Trade." *Review of Economics and Statistics*, 89(3): 416–435.

Santos Silva, João M.C., and Silvana Tenreyro. 2006. "The Log of Gravity." *Review of Economics and Statistics*, 88(4): 641–658.

Santos Silva, João M.C., and Silvana Tenreyro. 2011. "Further Simulation Evidence on the Performance of the Poisson Pseudo-Maximum Likelihood Estimator." *Economics Letters*, 112(2): 220–222.

StataCorp LP. 2013. "Stata Statistical Software: Release 13.1." College Station, Texas 77845 USA, http://www.stata.com/.

Waugh, Michael E. 2010. "International Trade and Income Differences." *American Economic Review*, 100(5): 2093–2124.

Windmeijer, Frank A. G., and João M.C. Santos Silva. 1997. "Endogeneity in Count Data Models: An Application to Demand for Health Care." *Journal of Applied Econometrics*, 12(3): 281–294.

Wooldridge, Jeffrey M. 1992. "Some Alternatives to the Box-Cox Regression Model." *International Economic Review*, 33(4): 935–955.

Table 1: Effects of Abolishing All International Borders Based on Estimated Trade Costs

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	'Conditional' GE				'Full Endowment' GE				
Country	Exports	RGDP	IMR	OMR	Exports	RGDP	IMR	OMR	p
ARG	41.46	6.65	-6.23	-16.32	67.42	26.55	-6.08	-18.25	18.86
AUS	107.00	4.64	-4.44	-12.15	135.49	19.01	-4.25	-14.13	13.95
AUT	26.45	8.26	-7.63	-17.50	52.07	30.35	-7.62	-19.48	20.41
BGR	6.58	11.15	-10.03	-19.29	30.79	36.39	-10.03	-21.24	22.72
BLX	49.02	6.31	-5.93	-15.32	75.26	25.15	-5.92	-17.34	17.73
BOL	6.93	13.60	-11.97	-20.25	32.18	40.28	-11.76	-22.03	23.78
BRA	92.92	2.12	-2.07	-11.98	118.85	15.89	-1.85	-13.95	13.75
CAN	24.94	14.13	-12.38	-19.95	52.92	39.45	-11.82	-21.44	22.97
CHE	36.40	6.57	-6.17	-16.41	62.20	26.89	-6.17	-18.42	19.07
CHL	43.96	7.73	-7.17	-16.22	70.14	27.64	-7.00	-18.13	18.70
CHN	87.73	-3.16	3.26	-14.18	117.15	12.58	3.35	-16.20	16.36
COL	43.45	10.56	-9.55	-16.69	70.07	31.32	-9.27	-18.49	19.15
CRI	53.79	10.42	-9.44	-15.77	80.47	29.87	-9.13	-17.57	18.01
DEU	64.05	0.00	0.00	-12.84	89.10	14.88	0.00	-14.94	14.88
DNK	29.69	8.20	-7.58	-17.37	55.68	30.05	-7.56	-19.34	20.23
ECU	37.89	11.74	-10.51	-16.96	64.12	33.17	-10.25	-18.78	19.52
ESP	64.12	5.13	-4.88	-13.69	89.94	21.66	-4.82	-15.72	15.79
FIN	30.04	6.46	-6.06	-17.10	55.60	27.61	-6.04	-19.09	19.91
FRA	58.78	4.10	-3.94	-14.19	84.68	21.12	-3.91	-16.23	16.39
GBR	101.41	2.83	-2.75	-10.74	127.97	15.49	-2.64	-12.78	12.44
GRC	47.52	9.24	-8.46	-15.13	73.20	28.35	-8.44	-17.17	17.52
HUN	25.77	8.04	-7.44	-17.17	50.81	29.71	-7.46	-19.19	20.04
IRL	31.69	3.25	-3.15	-16.97	57.04	23.42	-3.05	-18.89	19.66
ISL	14.77	11.61	-10.40	-19.34	40.48	36.58	-10.24	-21.16	22.60
ISR	94.86	3.22	-3.12	-11.45	121.28	16.71	-2.99	-13.48	13.22
ITA	67.22	2.65	-2.58	-13.13	92.87	18.20	-2.55	-15.20	15.18
JPN	112.71	-6.82	7.32	-11.78	142.22	5.65	7.49	-13.78	13.56
KOR	101.74	-2.18	2.23	-14.73	134.86	14.43	2.27	-16.77	17.03
MAR	19.52	10.35	-9.38	-18.25	44.74	33.71	-9.29	-20.16	21.29
MEX	54.33	10.89	-9.82	-17.01	82.57	31.53	-9.30	-18.61	19.30
NLD	50.78	4.76	-4.55	-15.13	76.93	23.07	-4.53	-17.15	17.50
NOR	28.39	9.05	-8.30	-17.30	54.00	30.96	-8.27	-19.27	20.14
POL	31.39	8.26	-7.63	-17.15	57.38	29.85	-7.61	-19.13	19.97
PRT	36.53	8.48	-7.81	-16.27	61.93	28.82	-7.75	-18.24	18.84
ROM	51.81	4.94	-4.71	-14.69	77.45	22.77	-4.70	-16.74	17.00
ROW	92.58	3.82	-3.68	-13.08	121.06	19.27	-3.54	-15.08	15.04
SWE	27.21	6.75	-6.32	-17.24	52.51	28.18	-6.31	-19.23	20.09
TUN	17.95	10.09	-9.17	-18.38	43.12	33.67	-9.11	-20.31	21.49
TUR	42.56	6.83	-6.39	-15.84	68.36	26.37	-6.35	-17.84	18.34
URY	14.52	10.98	-9.89	-18.95	39.66	35.44	-9.78	-20.85	22.19
USA	150.71	-1.08	1.09	-5.19	180.87	4.81	1.60	-7.07	6.49

Notes: This table reports results from the scenario of abolishing all international borders based on estimated trade costs. Column (1) lists the country abbreviations. Columns (2)-(5) report results from the 'Conditional' GE scenario, while columns (6)-(10) report results from the 'Full Endowment' scenario. Columns (2) and (6) report the percentage changes in total exports of a country. Columns (3) and (7) report the percentage changes in real GDP (which may be taken as a welfare measure). Column (4) and (8) report the percentage changes in the inward multilateral resistances (IMRs), and columns (5) and (9) the corresponding outward MRs (OMRs). The last column, column (10), reports the changes in producer prices. See text for further details.

Table 2: Effects of Abolishing All International Borders Based on "Estibrated" Trade Costst

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	'Conditional' GE				'Full Endowment' GE				
Country	Exports	RGDP	IMR	OMR	Exports	RGDP	IMR	OMR	p
ARG	109.44	-4.76	5.00	-13.41	142.50	10.00	5.20	-15.66	15.72
AUS	160.16	0.36	-0.36	-10.83	196.75	12.91	-0.11	-13.09	12.78
AUT	16.33	6.61	-6.20	-20.58	45.02	33.18	-6.23	-22.83	24.88
BGR	46.69	4.41	-4.22	-17.29	76.26	25.75	-4.16	-19.56	20.52
BLX	18.86	6.38	-5.99	-19.67	46.75	31.60	-6.03	-21.95	23.67
BOL	176.90	5.53	-5.24	-8.07	205.45	15.04	-4.73	-10.14	9.60
BRA	156.82	-5.17	5.45	-10.32	190.46	5.84	5.88	-12.45	12.07
CAN	31.44	9.95	-9.05	-21.77	64.44	37.37	-8.47	-23.45	25.74
CHE	40.96	3.20	-3.10	-18.24	71.19	25.68	-3.10	-20.54	21.78
CHL	113.73	-0.36	0.36	-13.53	147.58	15.22	0.56	-15.78	15.86
CHN	85.90	-7.12	7.67	-15.44	119.19	9.75	7.73	-17.75	18.24
COL	235.48	3.16	-3.06	-4.78	263.35	8.65	-2.32	-6.71	6.13
CRI	62.68	9.51	-8.69	-17.21	94.49	31.11	-8.39	-19.25	20.11
DEU	52.65	0.00	0.00	-16.37	82.02	19.43	0.00	-18.71	19.43
DNK	13.93	6.33	-5.95	-20.56	42.03	32.79	-5.98	-22.81	24.84
ECU	262.90	6.89	-6.45	-4.64	289.81	12.43	-5.72	-6.57	6.00
ESP	90.73	0.23	-0.23	-13.10	121.28	15.63	-0.13	-15.46	15.48
FIN	33.47	2.53	-2.46	-18.25	62.31	25.00	-2.53	-20.59	21.84
FRA	74.06	0.02	-0.02	-14.66	104.42	17.30	0.03	-17.01	17.33
GBR	65.48	2.63	-2.57	-15.33	95.56	21.26	-2.55	-17.69	18.16
GRC	104.22	4.76	-4.54	-12.33	135.31	19.94	-4.45	-14.70	14.60
HUN	19.29	6.10	-5.75	-20.05	47.86	31.81	-5.79	-22.33	24.18
IRL	12.76	6.87	-6.43	-20.82	40.79	33.52	-6.34	-22.96	25.05
ISL	89.03	1.38	-1.36	-12.44	118.85	16.32	-1.32	-14.86	14.78
ISR	74.54	2.20	-2.15	-15.38	105.66	20.56	-2.04	-17.64	18.10
ITA	79.91	-1.28	1.29	-14.49	110.75	15.50	1.38	-16.81	17.09
JPN	116.23	-7.82	8.48	-13.28	150.07	6.31	8.70	-15.52	15.55
KOR	90.35	-1.69	1.72	-15.92	125.23	16.68	1.81	-18.19	18.78
MAR	90.66	1.94	-1.90	-13.52	121.51	18.05	-1.78	-15.85	15.94
MEX	40.17	10.31	-9.34	-20.76	73.32	36.33	-8.76	-22.47	24.38
NLD	6.67	8.65	-7.96	-20.91	33.61	36.29	-8.02	-23.18	25.36
NOR	86.31	1.16	-1.15	-12.97	116.79	16.76	-1.15	-15.41	15.42
POL	78.44	0.89	-0.89	-14.04	109.10	17.73	-0.90	-16.47	16.68
PRT	56.27	4.06	-3.90	-16.10	85.77	23.85	-3.86	-18.42	19.07
ROM	160.52	-5.65	5.99	-9.03	195.87	3.91	6.53	-11.18	10.70
ROW	69.95	3.32	-3.21	-17.88	104.73	24.98	-3.07	-20.05	21.14
SWE	13.84	5.91	-5.58	-20.50	41.74	32.06	-5.56	-22.71	24.71
TUN	76.71	1.80	-1.77	-14.72	107.64	19.49	-1.73	-17.09	17.42
TUR	102.84	-0.85	0.86	-12.56	134.13	13.64	1.02	-14.87	14.80
URY	98.14	0.58	-0.57	-15.03	132.54	18.18	-0.44	-17.28	17.66
USA	146.33	-3.69	3.83	-8.05	183.95	5.23	4.26	-10.24	9.71

Notes: This table reports results from the scenario of abolishing all international borders based on "estibrated" trade costs. Column (1) lists the country abbreviations. Columns (2)-(5) report results from the 'Conditional' GE scenario, while columns (6)-(10) report results from the 'Full Endowment' scenario. Columns (2) and (6) report the percentage changes in total exports of a country. Columns (3) and (7) report the percentage changes in real GDP (which may be taken as a welfare measure). Column (4) and (8) report the percentage changes in the inward multilateral resistances (IMRs), and columns (5) and (9) the corresponding outward MRs (OMRs). The last column, column (10), reports the changes in producer prices. See text for further details.

Table 3: 'Full Endowment' GE Effects of Abolishing International Borders Between US and Canada based on "Estibrated" Trade Costs

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Border between US and Canada is abolished					Only border to the US is abolished				
Country	Exports	RGDP	IMR	OMR	p	Exports	RGDP	IMR	OMR	p
ARG	-0.14	-0.03	0.03	0.01	0.00	0.10	0.00	-0.05	0.05	-0.05
AUS	-1.06	-0.08	0.00	0.09	-0.08	0.46	0.02	0.03	-0.06	0.05
AUT	-0.03	-0.08	0.01	0.08	-0.07	0.05	0.01	0.01	-0.02	0.02
BGR	-0.03	-0.04	-0.03	0.07	-0.06	0.06	0.00	0.01	-0.01	0.01
BLX	0.01	-0.06	0.03	0.04	-0.04	0.02	-0.01	0.01	0.00	0.00
BOL	-0.32	-0.04	0.09	-0.06	0.05	-0.10	-0.01	-0.05	0.07	-0.06
BRA	-0.68	-0.04	0.04	0.00	0.00	-0.11	-0.01	-0.03	0.05	-0.04
CAN	51.74	34.06	-12.73	-16.74	17.00	40.60	13.93	3.28	-17.29	17.67
CHE	-0.09	-0.06	-0.01	0.08	-0.07	0.07	0.01	-0.01	0.00	0.00
CHL	-0.62	-0.08	0.08	0.00	0.00	-0.11	-0.02	0.03	-0.01	0.01
CHN	-0.11	-0.03	-0.06	0.11	-0.10	0.09	0.00	-0.02	0.03	-0.02
COL	-0.67	-0.04	0.21	-0.21	0.18	-0.61	-0.02	-0.06	0.10	-0.09
CRI	-0.76	-0.21	0.28	-0.09	0.08	-0.25	-0.03	-0.13	0.19	-0.16
DEU	-0.10	-0.05	0.00	0.06	-0.05	0.03	0.00	0.00	0.00	0.00
DNK	-0.04	-0.11	0.06	0.06	-0.05	0.01	-0.04	0.08	-0.04	0.04
ECU	-0.56	-0.04	0.16	-0.15	0.13	-0.37	-0.02	-0.08	0.11	-0.10
ESP	0.02	-0.02	-0.02	0.05	-0.04	0.05	-0.01	0.01	-0.01	0.01
FIN	-0.03	-0.05	-0.02	0.07	-0.06	0.10	0.02	0.00	-0.03	0.02
FRA	-0.15	-0.05	-0.01	0.06	-0.05	0.10	0.00	0.00	-0.01	0.01
GBR	-0.42	-0.10	0.06	0.05	-0.04	-0.02	-0.01	0.04	-0.03	0.03
GRC	-0.10	-0.03	-0.02	0.06	-0.05	0.11	0.00	0.01	-0.01	0.01
HUN	0.06	-0.02	-0.01	0.04	-0.03	0.00	-0.02	0.00	0.02	-0.01
IRL	-0.09	-0.13	0.07	0.06	-0.05	-0.04	-0.02	-0.01	0.04	-0.03
ISL	-0.18	-0.04	0.02	0.02	-0.02	0.19	0.01	0.03	-0.04	0.04
ISR	-0.18	-0.06	0.04	0.02	-0.02	-0.12	-0.02	-0.04	0.07	-0.06
ITA	-0.15	-0.04	-0.03	0.08	-0.07	0.10	0.00	0.01	-0.01	0.01
JPN	-0.55	-0.05	-0.03	0.09	-0.08	-0.02	-0.01	-0.02	0.03	-0.02
KOR	-0.51	-0.09	0.02	0.08	-0.07	0.00	0.00	-0.01	0.02	-0.01
MAR	0.09	-0.01	-0.01	0.03	-0.03	0.06	0.00	-0.01	0.01	-0.01
MEX	-1.51	-0.47	0.38	0.12	-0.10	-0.22	0.00	-0.11	0.13	-0.11
NLD	0.04	-0.08	0.04	0.04	-0.04	0.04	0.01	-0.01	-0.01	0.01
NOR	-0.81	-0.12	0.15	-0.03	0.03	-0.43	-0.06	0.20	-0.15	0.13
POL	0.05	-0.02	-0.03	0.06	-0.05	0.10	0.00	0.01	-0.01	0.01
PRT	0.03	-0.02	-0.02	0.05	-0.04	0.04	-0.01	0.01	-0.01	0.01
ROM	0.06	-0.01	-0.06	0.07	-0.06	0.16	0.00	0.00	0.00	0.00
ROW	-0.35	-0.09	0.03	0.06	-0.05	-0.14	-0.03	-0.02	0.05	-0.04
SWE	-0.08	-0.09	0.00	0.11	-0.09	0.09	0.04	0.00	-0.06	0.05
TUN	0.11	-0.01	-0.03	0.05	-0.04	0.05	-0.01	0.01	0.00	0.00
TUR	-0.07	-0.03	-0.01	0.05	-0.04	0.06	0.00	-0.01	0.02	-0.01
URY	-0.19	-0.05	-0.01	0.06	-0.05	0.26	0.02	-0.03	0.00	0.00
USA	18.97	0.54	0.01	-0.64	0.55	9.28	0.27	-0.58	0.36	-0.31

Notes: This table reports results from the 'Full Endowment' GE scenario of abolishing international borders between the US and Canada. All results are based on "estibrated" trade costs. Column (1) lists the country abbreviations. Columns (2)-(6) report results when the international borders between US and Canada are abolished in both directions, while columns (7)-(11) report results when only the border for imports into the US are abolished. Columns (2) and (7) report the percentage changes in total exports of a country. Columns (3) and (8) report the percentage changes in real GDP (which may be taken as a welfare measure). Column (4) and (9) report the percentage changes in the inward multilateral resistances (IMRs), and columns (5) and (10) the corresponding outward MRs (OMRs). Columns (6) and (11) report the changes in producer prices. See text for further details.

Appendices

A Beyond the Endowment Environment

We demonstrated how to estimate general equilibrium effects in an endowment setting, where the value of income/production is endogenous but only due to changes in factory-gate prices. (Equivalently, income in the Ricardian Eaton-Kortum setting endogenous due to changes in the wages times the endowments of labor.)

Our procedures for calculating conditional general equilibrium comparative statics apply more generally. They can nest in any general equilibrium superstructure that endogenizes the 'endowments' vector for each country while embedding inward multilateral resistances in national expenditure functions and national profit functions. Sufficient conditions include internationally identical CES tastes (for final goods) and technology (for intermediate goods) in each sector, and in the Ricardian Eaton-Kortum version an internationally common Fréchet distribution for productivity draws (with nationally distinct absolute advantage location parameters) to justify the sectoral structural gravity structures. The vector of sectoral CES final goods price indexes facing each country determines expenditure allocation across sectors in each country's upper level expenditure function. The vector of CES intermediate goods price indexes in each country partly determines intermediate goods expenditure allocation across sectors as an argument in each country's national profit (GDP) function. Caliendo and Parro (2015) is an example that satisfies these restrictions in the Ricardian Eaton-Kortum case.

Another possible channel to endogenize production is via asset accumulation. For example, Anderson, Larch and Yotov (2015) combine the Armington-CES gravity model with a dynamic model of capital accumulation. Another possible channel is through labor-leisure choice. These two possibilities retain the one-good national economy.

The idea for full general equilibrium comparative statics remains essentially the same. The conditional general equilibrium gravity modules in each sector deliver multilateral resistances to the superstructure module. Reallocation of factors and of expenditure on intermediate and final goods sectoral aggregates occurs. The new values are passed back to the sectoral conditional general equilibrium modules and new multilateral resistances are generated. These are passed back to the superstructure and reallocation occurs again. The process continues until convergence.

It is possible that other algorithms may be more efficient still. But the modular structure of our suggested approach preserves insight into what is driving the ultimate equilibrium comparative statics.

B Appendix: Implementation in Stata

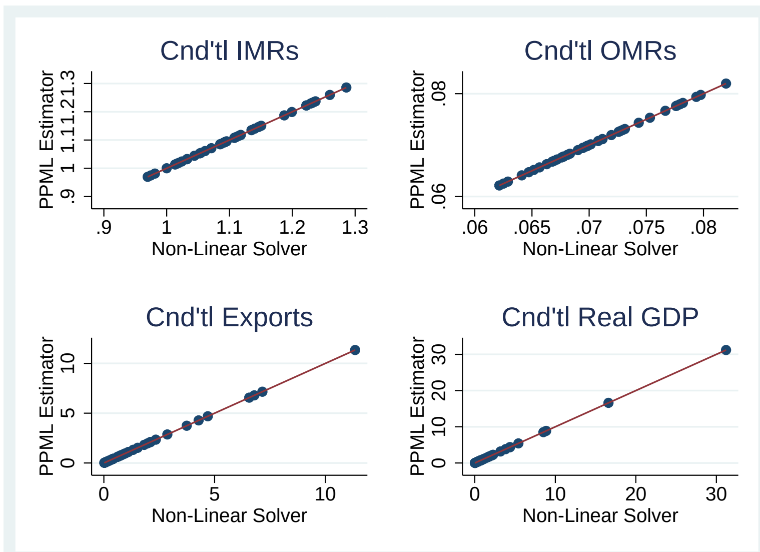
This appendix provides the Stata code that corresponds to the three main steps from our procedure. The actual Stata ‘data’ and ‘do’ files used to obtain the GE indexes from the main text are available by request.

Stata Commands | **Comment/Description**

```
****************************************
* Step 1.a: Estimate ‘Baseline’ Gravity*
****************************************
qui tab exporter                                                                   *Obtain number of countries
local NoC=r(r)
scalar sigma=7                                                                     *Define sigma.
ppml X_ij LN_DIST CNTG BRDR exp_fe_* imp_fe_1-imp_fe_‘=‘NoC’-1’, iter(30) noconst   *Obtain trade cost elasticities using Eq. (9).
predict hat_X_ij, mu                                                               *Save predicted trade.
scalar DIST_est=_b[LN_DIST]                                                        *Save estimates of trade cost elasticities.
scalar CNTG_est=_b[CNTG]
gen t_ij_bsln=exp(_b[LN_DIST]*LN_DIST+_b[CNTG]*CNTG+_b[BRDR]*BRDR)                 *Construct baseline t_ij^(1-sigma)
gen t_ij_ctrf=exp(_b[LN_DIST]*LN_DIST+_b[CNTG]*CNTG+_b[BRDR]*BRDR*0)               *Construct counterfactual t_ij^(1-sigma)
gen t_ij_ctrf_1=log(t_ij_ctrf)
********************************************
* Step 1.b: Construct ‘Baseline’ GE Indexes*
********************************************
forvalues i=1(1)‘=‘NoC’-1’{                                                        *Combine estimates of fixed effects.
qui replace exp_fe_‘i’=exp_fe_‘i’*exp(_b[exp_fe_‘i’])
qui replace imp_fe_‘i’=imp_fe_‘i’*exp(_b[imp_fe_‘i’])
}
qui replace exp_fe_‘NoC’=exp_fe_‘NoC’*exp(_b[exp_fe_‘NoC’])
qui replace imp_fe_‘NoC’=imp_fe_‘NoC’*exp(0)
egen all_exp_fes_0=rowtotal(exp_fe_1-exp_fe_‘=‘NoC’)
egen all_imp_fes_0=rowtotal(imp_fe_1-imp_fe_‘=‘NoC’)
gen omr_bsln=Y_i*E_deu/(all_exp_fes_0)                                             *Construct OMRs from Eq. (7).
gen imr_bsln=E_j/(all_imp_fes_0*E_deu)                                             *Construct IMRs from Eq. (8).
gen real_gdp_bsln=Y_i/(imr_bsln^(1/(1-sigma)))                                     *Construct Real GDP.
*******************************************
* Step 2.a: Estimate ‘Conditional’ Gravity*
*******************************************
drop exp_fe_* imp_fe_*                                                             *Drop estimated FEs as they will be updated.
qui tab exporter, gen(exp_fe_)                                                     *Create new FEs.
qui tab importer, gen(imp_fe_)
ppml trade exp_fe_* imp_fe_1-imp_fe_‘=‘NoC’-1’, iter(30) noconst offset(t_ij_ctrf_1)   *Obtain ‘Conditional’ FEs from Eq. (13).
predict trade_cndl, mu                                                             *Save predicted trade for Step 3.
******************************************************************************************************************************
* Step 2.b: Repeat Step 1.b with the new fixed effects and original trade data to obtain the ‘Conditional’ GE indexes of interest.     *
******************************************************************************************************************************
*********************************************
* Step 3.a: Estimate ‘Full Endowment’ Gravity*
*********************************************
local i=3                                                                          *Define loop and stopping criteria values.
local diff_all_exp_fes_sd=1
local diff_all_exp_fes_max=1
while (‘diff_all_exp_fes_sd’>0.01) | (‘diff_all_exp_fes_max’>0.01) {
gen trade_‘=‘i’-1’=trade_‘=‘i’-2’_pred* ///                                        *Update trade according to Eq. (16).
p_full_exp_‘=‘i’-2’*p_full_imp_‘=‘i’-2’/(omr_full_ch_‘=‘i’-2’*imr_full_ch_‘=‘i’-2’)
drop exp_fe_* imp_fe_*                                                             *Drop estimated FEs as they will be updated.
qui tab exporter, gen(exp_fe_)
qui tab importer, gen(imp_fe_)
capture glm trade_‘=‘i’-1’ exp_fe_* imp_fe_*, offset(t_ij_ctrf_1) family(poisson) ///   *Estimate Eq. (13) with new trade values.
noconst irls iter(30)
predict trade_‘=‘i’-1’_pred, mu
forvalues j=1(1)‘NoC’{                                                             *Combine updated estimates of fixed effects.
qui replace exp_fe_‘j’=exp_fe_‘j’*exp(_b[exp_fe_‘j’])
qui replace imp_fe_‘j’=imp_fe_‘j’*exp(_b[imp_fe_‘j’])
}
egen double all_exp_fes_‘=‘i’-1’=rowtotal(exp_fe_1-exp_fe_‘NoC’)
egen double all_imp_fes_‘=‘i’-1’=rowtotal(imp_fe_1-imp_fe_‘NoC’)
bysort exporter: egen double output_‘=‘i’-1’=total(trade_‘=‘i’-1’_pred)            *Update output
bysort importer: egen double expndr_check_‘=‘i’-1’=total(trade_‘=‘i’-1’_pred)      *Update expenditure
gen double expndr_deu0_‘=‘i’-1’=expndr_check_‘=‘i’-1’ if importer=="ZZZ"
egen double expndr_deu_‘=‘i’-1’=mean(expndr_deu0_‘=‘i’-1’)
gen double temp=all_exp_fes_‘=‘i’-1’ if exporter==importer
bysort importer: egen double all_exp_fes_‘=‘i’-1’_imp=mean(temp)
drop temp*
gen double p_full_exp_‘=‘i’-1’=((all_exp_fes_‘=‘i’-1’/all_exp_fes_‘=‘i’-2’)///      *Update factory-gate prices according to Eq. (19)
(expndr_deu_‘=‘i’-1’/expndr_deu_‘=‘i’-2’))^(1/(1-sigma))
gen double p_full_imp_‘=‘i’-1’=((all_exp_fes_‘=‘i’-1’_imp/all_exp_fes_‘=‘i’-2’_imp)/(expndr_deu_‘=‘i’-1’/expndr_deu_‘=‘i’-2’))^(1/(1-sigma))
gen double omr_full_‘=‘i’-1’=(output_‘=‘i’-1’**expndr_deu_‘=‘i’-1’)/all_exp_fes_‘=‘i’-1’   *Equation (17)
gen double omr_full_ch_‘=‘i’-1’=omr_full_‘=‘i’-1’/omr_full_‘=‘i’-2’
gen double expndr_temp_‘=‘i’-1’=phi*output_‘=‘i’-1’ if exporter==importer           *Update expenditure
bysort importer: egen double expndr_‘=‘i’-1’=mean(expndr_temp_‘=‘i’-1’)
gen double imr_full_‘=‘i’-1’=expndr_‘=‘i’-1’/(all_imp_fes_‘=‘i’-1’*expndr_deu_‘=‘i’-1’)    *Equation (18)
gen double imr_full_ch_‘=‘i’-1’=imr_full_‘=‘i’-1’/imr_full_‘=‘i’-2’
gen double diff_p_full_exp_‘=‘i’-1’=p_full_exp_‘=‘i’-2’-p_full_exp_‘=‘i’-3’         *Convergence criteria in terms of changes
sum diff_p_full_exp_‘=‘i’-1’                                                         in factory-gate prices
local diff_all_exp_fes_sd=r(sd)
local diff_all_exp_fes_max=abs(r(max))
local i=‘i’+1
}
******************************************************************************************************************************
* Step 3.b: Repeat Step 1.b with the new fixed effects and the new trade values to obtain the ‘Full Endowment’ GE indexes of interest. *
******************************************************************************************************************************
```

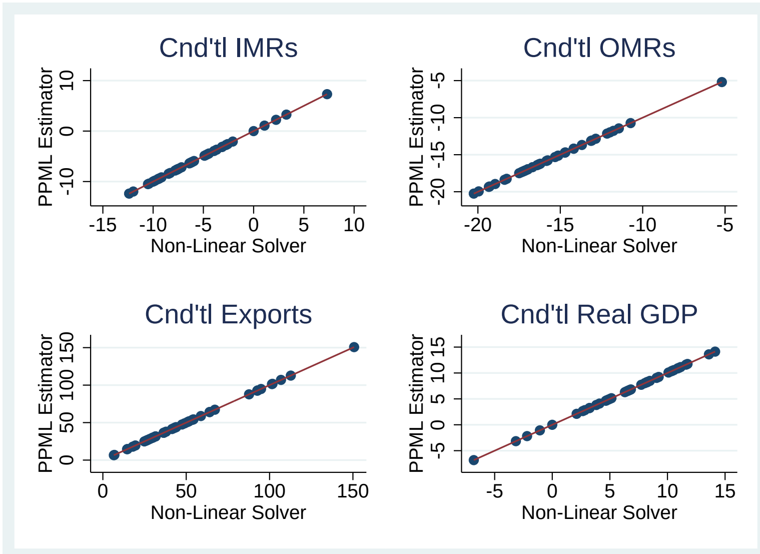
C Figures Comparing Matlab versus Stata Results

Figure A1 shows that the levels of the 'Conditional' GE equilibrium for the IMRs, OMRs, total exports and real GDP from the estimation in Stata and from the solution of the nonlinear gravity system (in Matlab) are identical. Figure A2 demonstrates that this is also true for the percentage changes in the GE indexes from the 'Baseline' to the 'Conditional' GE scenario. Figure A3 confirms the equivalence between the two methods concerning the level of the variables in the 'Full Endowment' GE scenario. This again holds for the percentage changes between the 'Baseline' and the 'Full Endowment' GE indexes, which are plotted in Figure A4. Figure A5 confirms the equivalence between the two methods with respect to the changes in consumer prices/IMRs, total exports and real GDP for the 'Full Endowment' Ge scenario based on "estibrated" rather than estimated trade costs. Thus, we establish that our methods can indeed deliver results that are identical to those obtained with the 'exact hat' algebra procedures from Dekle, Eaton and Kortum (2007, 2008).



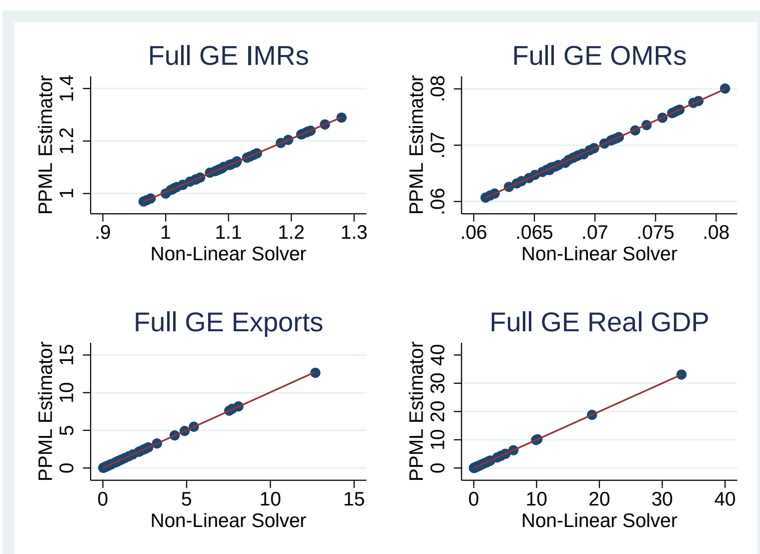
Note: These figures compare the results from Matlab and Stata for (clockwise, starting from the upper left) the IMR, OMR, the real GDP (in 100m dollars), and total exports (in 100m dollars) of each country for the 'Conditional' GE effects when abandoning international borders.

Figure A1: 'Conditional' GE Results: Matlab versus Stata



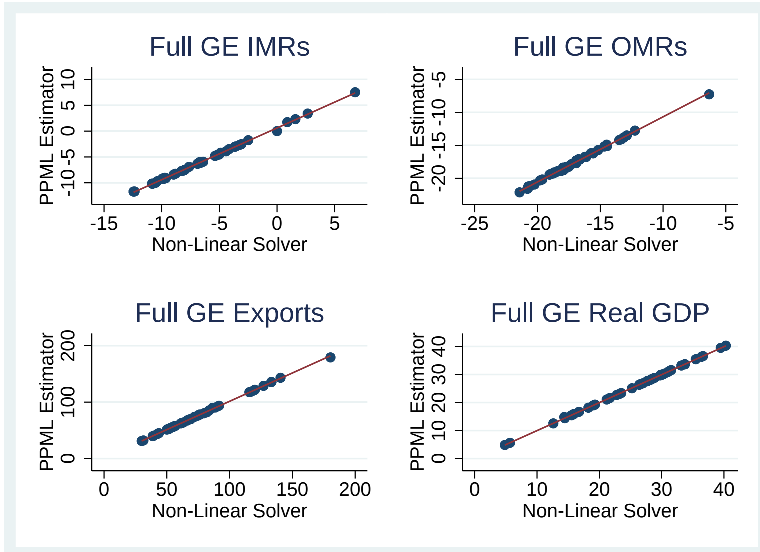
Note: These figures compare the results from Matlab and Stata for (clockwise, starting from the upper left) the changes (in percent) of the IMR, the changes (in percent) of the OMR, welfare effects in percent (calculated as changes in real GDP), and the changes (in percent) of total exports of each country for the 'Conditional' GE effects when abandoning international borders.

Figure A2: 'Conditional' GE Indexes: Matlab versus Stata



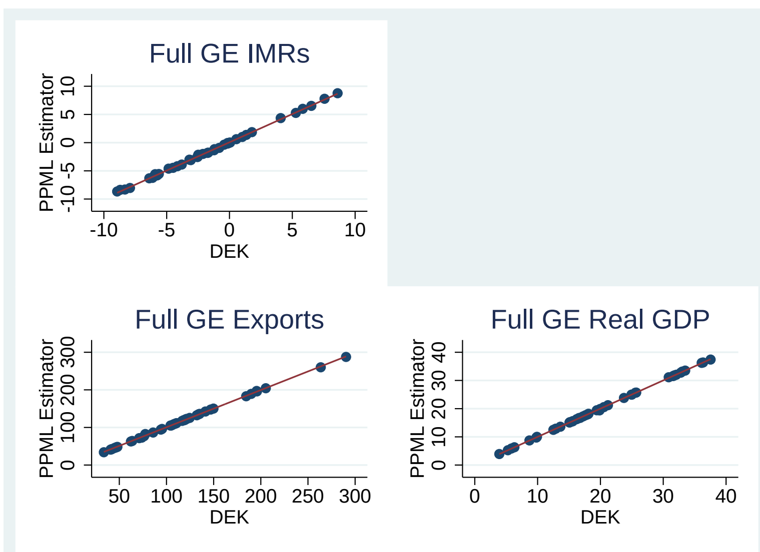
Note: These figures compare the results from Matlab and Stata for (clockwise, starting from the upper left) the IMR, OMR, the real GDP (in 100m dollars), and total exports (in 100m dollars) of each country for the 'Full Endowment' GE effects when abandoning international borders.

Figure A3: 'Full Endowment' GE Results: Matlab versus Stata



Note: These figures compare the results from Matlab and Stata for (clockwise, starting from the upper left) the changes (in percent) of the IMR, the changes (in percent) of the OMR, welfare effects in percent (calculated as changes in real GDP), and the changes (in percent) of total exports of each country for the 'Full Endowment' GE effects when abandoning international borders.

Figure A4: 'Full Endowment' GE Indexes: Matlab versus Stata



Note: These figures compare the results from Matlab solving the system in changes following Dekle, Eaton and Kortum (2007, 2008) (DEK) and Stata for (clockwise, starting from the upper left) the changes (in percent) of the IMR, welfare effects in percent (calculated as changes in real GDP), and the changes (in percent) of total exports of each country for the 'Full Endowment' GE effects when abandoning international borders.

Figure A5: 'Full Endowment' GE Indexes: Dekle, Eaton and Kortum (2007, 2008) (DEK) versus Stata

D Solving the System in Changes Following Dekle, Eaton and Kortum (2007, 2008)

In this appendix we derive the system in changes following Dekle, Eaton and Kortum (2007, 2008) and as summarized in Costinot and Rodríguez-Clare (2014). We start with trade flows given by:

$$X_{ij} = \left(\frac{\gamma_i p_i t_{ij}}{P_j}\right)^{1-\sigma} E_j.$$

Using the expression for the price index $P_j^{1-\sigma} = \sum_i \left(\gamma_i p_i t_{ij}\right)^{1-\sigma}$ we can express trade flows as:

$$X_{ij} = \frac{\left(\gamma_i p_i t_{ij}\right)^{1-\sigma}}{\sum_k \left(\gamma_k p_k t_{kj}\right)^{1-\sigma}} E_j.$$

Each country is endowed with a fixed endowment Q, and hence the total value of output can be expressed as $Y_i = p_i Q_i$. We therefore can replace p_i by Y_i/Q_i in our trade flow equation:

$$X_{ij} = \frac{\left(\gamma_i Y_i t_{ij}/Q_i\right)^{1-\sigma}}{\sum_k \left(\gamma_k Y_k t_{kj}/Q_k\right)^{1-\sigma}} E_j.$$

From market clearance we have $Y_i = \sum_j X_{ij}$. Further, it holds that $E_i = \phi_i Y_i$. Hence, we can write:

$$Y_i = \sum_j \frac{\left(\gamma_i Y_i t_{ij}/Q_i\right)^{1-\sigma}}{\sum_k \left(\gamma_k Y_k t_{kj}/Q_k\right)^{1-\sigma}} \phi_j Y_j.$$

Let $\lambda_{ij} = X_{ij}/\sum_k X_{kj} = X_{ij}/E_j$ denote the share of expenditure on goods from country i in country j. We can write λ_{ij} as:

$$\lambda_{ij} = \frac{X_{ij}}{E_j} = \frac{\frac{\left(\gamma_i Y_i t_{ij}/Q_i\right)^{1-\sigma}}{\sum_k \left(\gamma_k Y_k t_{kj}/Q_k\right)^{1-\sigma}} E_j}{E_j} = \frac{\left(\gamma_i Y_i t_{ij}/Q_i\right)^{1-\sigma}}{\sum_l \left(\gamma_l Y_l t_{lj}/Q_l\right)^{1-\sigma}}.$$

The change in λ_{ij}, $\widehat{\lambda}_{ij} = \lambda_{ij}^c/\lambda_{ij}^b$, is then given by:

$$\begin{aligned}
\widehat{\lambda}_{ij} &= \frac{\frac{\left(\gamma_i Y_i^c t_{ij}^c/Q_i\right)^{1-\sigma}}{\sum_l \left(\gamma_l Y_l^c t_{lj}^c/Q_l\right)^{1-\sigma}}}{\frac{\left(\gamma_i Y_i^b t_{ij}^b/Q_i\right)^{1-\sigma}}{\sum_l \left(\gamma_l Y_l^b t_{lj}^b/Q_l\right)^{1-\sigma}}} = \frac{\left(\widehat{Y}_i \widehat{t}_{ij}\right)^{1-\sigma}}{\frac{\sum_l \left(\gamma_l Y_l^c t_{lj}^c/Q_l\right)^{1-\sigma}}{\sum_l \left(\gamma_l Y_l^b t_{lj}^b/Q_l\right)^{1-\sigma}}} = \frac{\left(\widehat{Y}_i \widehat{t}_{ij}\right)^{1-\sigma}}{\sum_l \lambda_{lj}^b \left(\gamma_l Y_l^b t_{lj}^b/Q_l\right)^{\sigma-1} \left(\gamma_l Y_l^c t_{lj}^c/Q_l\right)^{1-\sigma}} \\
&= \frac{\left(\widehat{Y}_i \widehat{t}_{ij}\right)^{1-\sigma}}{\sum_l \lambda_{lj}^b \left(\widehat{Y}_l \widehat{t}_{lj}\right)^{1-\sigma}}. \qquad \text{(A1)}
\end{aligned}$$

Counterfactual income levels can be written as:

$$Y_i^c = \sum_j \frac{\left(\gamma_i Y_i^c t_{ij}^c / Q_i\right)^{1-\sigma}}{\sum_k \left(\gamma_k Y_k^c t_{kj}^c / Q_k\right)^{1-\sigma}} \phi_j Y_j^c = \sum_j \lambda_{ij}^c \phi_j Y_j^c, \tag{A2}$$

using $\lambda_{ij}^c = \frac{(\gamma_i Y_i t_{ij}/Q_i)^{1-\sigma}}{\sum_l \left(\gamma_l Y_l t_{lj}/Q_l\right)^{1-\sigma}}$.

Combining Equations (A1) and (A2), we can write:

$$Y_i^c = \sum_j \lambda_{ij}^c \phi_j Y_j^c \Rightarrow \frac{Y_i^c}{Y_i^b} Y_i^b = \sum_j \frac{\lambda_{ij}^c}{\lambda_{ij}^b} \lambda_{ij}^b \phi_j \frac{Y_j^c}{Y_j^b} Y_j^b \Rightarrow$$

$$\widehat{Y}_i Y_i^b = \sum_j \frac{\lambda_{ij}^b \left(\widehat{Y}_i \widehat{t}_{ij}\right)^{1-\sigma}}{\sum_l \lambda_{lj}^b \left(\widehat{Y}_l \widehat{t}_{lj}\right)^{1-\sigma}} \phi_j \widehat{Y}_j Y_j^b.$$

This equation system can be solved for the n-unknown $\widehat{Y}$'s, given λ_{ij}^b's, $\widehat{t}_{ij}$'s, Y_j^b's, and ϕ_j's up to a scalar, i.e. we have to set one change of $\widehat{Y}$ to one.

Given the solved $\widehat{Y}$'s, we can solve for $\widehat{\lambda}_{ij}$ using Equation (A1). Then we can use the formula of Arkolakis, Costinot and Rodríguez-Clare (2012) to calculate the change in welfare (real GDP) by $\widehat{W}_i = \widehat{\lambda}_{ii}^{\frac{1}{1-\sigma}}$.

If we are interested in the change of total exports, we first have to calculate the counterfactual values of bilateral exports. We can use $X_{ij} = \lambda_{ij} E_j = \lambda_{ij} \phi_j Y_j$ and $\widehat{E}_j = \widehat{Y}_j$ to write:

$$X_{ij}^c = \widehat{\lambda}_{ij} \lambda_{ij}^b \widehat{Y}_j \phi_j Y_j^b.$$

Then we can simply calculate the change in bilateral exports as $\widehat{X}_{ij} = X_{ij}^c / X_{ij}^b$. The change in total exports can be calculated by $\widehat{X}_i = \sum_j X_{ij}^c / \sum_j X_{ij}^b$.

Note that we normalized $\widehat{Y}$ for one country when solving the system in changes following Dekle, Eaton and Kortum (2007, 2008). However, when using PPML, we have normalized the inward price index for one country to one. We can re-normalize by calculating the change in the price index as follows:

$$\widehat{P}_j = \frac{P_j^c}{P_j^b} = \frac{\left[\sum_i \left(\gamma_i p_i^c t_{ij}^c\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}}{\left[\sum_i \left(\gamma_i p_i^b t_{ij}^b\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}} = \left[\frac{\sum_i \left(\gamma_i p_i^c t_{ij}^c\right)^{1-\sigma}}{\sum_i \left(\gamma_i p_i^b t_{ij}^b\right)^{1-\sigma}}\right]^{\frac{1}{1-\sigma}}$$

$$= \left[\sum_i \lambda_{ij}^b \left(\gamma_i p_i^b t_{ij}^b\right)^{1-\sigma} \left(\gamma_i p_i^c t_{ij}^c\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}} = \left[\sum_i \lambda_{ij}^b \left(\widehat{p}_j \widehat{t}_{ij}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$$

$$= \left[\sum_i \lambda_{ij}^b \left(\widehat{Y}_j \widehat{t}_{ij}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}.$$

E ‘Full Endowment’ GE Effects of Abolishing International Borders Between US and Canada Based on Estimated Trade Costs

Table A1: ‘Full Endowment’ GE Effects of Abolishing International Borders Between US and Canada Based on Estimated Trade Costs

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Border between US and Canada is abolished					Only border to the US is abolished				
Country	Exports	RGDP	IMR	OMR	p	Exports	RGDP	IMR	OMR	p
ARG	-0.52	-0.19	0.14	0.06	-0.05	-0.28	-0.06	0.00	0.07	-0.06
AUS	-0.94	-0.12	0.08	0.05	-0.04	-0.42	-0.04	0.00	0.05	-0.04
AUT	-0.08	-0.08	0.03	0.06	-0.05	-0.05	-0.02	0.01	0.02	-0.01
BGR	-0.03	-0.14	0.07	0.08	-0.07	-0.04	-0.04	0.02	0.02	-0.02
BLX	-0.09	-0.06	0.01	0.05	-0.04	-0.05	-0.01	0.01	0.01	-0.01
BOL	-0.25	-0.41	0.29	0.14	-0.12	-0.18	-0.14	0.04	0.11	-0.09
BRA	-1.17	-0.15	0.12	0.04	-0.03	-0.51	-0.05	0.00	0.05	-0.05
CAN	42.09	34.95	-13.72	-16.27	16.44	33.57	14.09	2.27	-16.47	16.68
CHE	-0.06	-0.06	0.01	0.05	-0.05	-0.04	-0.02	0.00	0.01	-0.01
CHL	-0.74	-0.24	0.19	0.07	-0.06	-0.37	-0.08	0.01	0.08	-0.07
CHN	-0.39	-0.06	-0.06	0.14	-0.12	-0.14	-0.01	-0.05	0.07	-0.06
COL	-1.21	-0.39	0.34	0.06	-0.05	-0.57	-0.13	0.05	0.10	-0.09
CRI	-1.49	-0.39	0.37	0.03	-0.02	-0.71	-0.14	0.04	0.12	-0.10
DEU	-0.15	-0.05	0.00	0.06	-0.05	-0.07	-0.01	0.00	0.01	-0.01
DNK	-0.16	-0.10	0.04	0.07	-0.06	-0.08	-0.03	0.01	0.02	-0.01
ECU	-1.07	-0.40	0.36	0.06	-0.05	-0.53	-0.14	0.06	0.10	-0.09
ESP	-0.43	-0.10	0.06	0.05	-0.04	-0.18	-0.03	0.02	0.01	-0.01
FIN	-0.30	-0.15	0.07	0.10	-0.08	-0.12	-0.04	0.02	0.02	-0.02
FRA	-0.19	-0.07	0.02	0.05	-0.04	-0.09	-0.02	0.01	0.01	-0.01
GBR	-0.48	-0.07	0.03	0.04	-0.04	-0.19	-0.02	0.02	0.00	0.00
GRC	-0.31	-0.12	0.08	0.05	-0.04	-0.15	-0.04	0.03	0.01	-0.01
HUN	-0.12	-0.10	0.05	0.07	-0.06	-0.07	-0.03	0.01	0.02	-0.01
IRL	-0.20	-0.10	0.03	0.08	-0.07	-0.08	-0.02	0.00	0.02	-0.02
ISL	-0.51	-0.41	0.25	0.19	-0.16	-0.17	-0.11	0.08	0.03	-0.03
ISR	-0.50	-0.08	0.04	0.04	-0.04	-0.21	-0.02	0.01	0.01	-0.01
ITA	-0.26	-0.07	0.02	0.05	-0.05	-0.11	-0.02	0.01	0.01	-0.01
JPN	-0.37	-0.03	-0.10	0.16	-0.13	-0.11	-0.01	-0.07	0.09	-0.07
KOR	-0.25	-0.04	-0.08	0.15	-0.13	-0.10	-0.01	-0.06	0.08	-0.07
MAR	-0.30	-0.23	0.14	0.10	-0.09	-0.14	-0.07	0.04	0.03	-0.03
MEX	-1.48	-0.38	0.37	0.01	-0.01	-0.92	-0.16	-0.14	0.35	-0.30
NLD	-0.11	-0.06	0.01	0.05	-0.05	-0.06	-0.01	0.00	0.01	-0.01
NOR	-0.30	-0.17	0.09	0.09	-0.08	-0.13	-0.05	0.03	0.02	-0.02
POL	-0.17	-0.11	0.05	0.07	-0.06	-0.09	-0.03	0.01	0.02	-0.02
PRT	-0.37	-0.16	0.10	0.07	-0.06	-0.16	-0.05	0.03	0.01	-0.01
ROM	-0.28	-0.09	0.04	0.06	-0.05	-0.13	-0.02	0.01	0.02	-0.01
ROW	-0.83	-0.12	0.05	0.08	-0.07	-0.33	-0.03	0.00	0.04	-0.03
SWE	-0.22	-0.13	0.06	0.09	-0.07	-0.10	-0.03	0.01	0.02	-0.02
TUN	-0.17	-0.16	0.09	0.09	-0.07	-0.09	-0.05	0.02	0.03	-0.02
TUR	-0.32	-0.12	0.07	0.07	-0.06	-0.14	-0.03	0.02	0.02	-0.02
URY	-0.21	-0.24	0.17	0.08	-0.07	-0.17	-0.08	0.01	0.08	-0.07
USA	20.18	0.52	-0.07	-0.53	0.46	9.99	0.27	-0.79	0.61	-0.52

Notes: This table reports results from the ‘Full Endowment’ GE scenario of abolishing international borders between the US and Canada. All results are based on estimated trade costs. Column (1) lists the country abbreviations. Columns (2)-(6) report results when the international borders between US and Canada are abolished in both directions, while columns (7)-(11) report results when only the border for imports into the US are abolished. Columns (2) and (7) report the percentage changes in total exports of a country. Columns (3) and (8) report the percentage changes in real GDP (which may be taken as a welfare measure). Column (4) and (9) report the percentage changes in the inward multilateral resistances (IMRs), and columns (5) and (10) the corresponding outward MRs (OMRs). Columns (6) and (11) report the changes in producer prices. See text for further details.