Structural Constrained ANOVA-type Estimation of Gravity Panel Data Models

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January, 2013

Abstract

In most gravity model applications, general equilibrium effects are disregarded altogether or "controlled for" by country or country-time fixed effects, and the parameter estimates on observable trade cost variables are falsely interpreted as reduced-form marginal effects rather than only direct effects of such variables on trade. This paper proposes an empirical approach which employs panel data and, apart from bilateral trade data, employs fixed country-pair effects and fixed country-time effects only. Parameters are estimated by Poisson pseudo-maximum likelihood, imposing structural constraints that ensure alignment of estimation with theory. This approach represents a large class of trade models in both estimation and comparative static analysis. Mainly due to the presence of country-pair fixed effects, the framework exhibits a high explanatory power which considerably exceeds the one of traditional models that are based on observable trade cost variables. In a panel data-set of bilateral trade among OECD countries, the correlation coefficient between the model predictions and the data amounts to 0.96. We illustrate how general equilibrium consistent comparative static analysis can be conducted, and how the results compare with non-structural direct effects.

Keywords: Gravity models; Structural general equilibrium models; Welfare gains.

JEL-codes: F14.

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1 Introduction

The gravity equation is undoubtedly the most popular tool in empirical international economics. Main reasons for this are its straightforward implementation and its close fit to the data. However, while ad-hoc estimation is easy, it provides little value in terms of identifying structural parameters or predicting how trade would change in response to a counterfactual shock. On the other hand, current structural estimation approaches are not as easy to implement and often exhibit relatively modest explanatory power so that there is a chance of bias accruing to omitted variables.

This paper proposes a radically parsimonious empirical model which relies on observations of bilateral trade flow panel data only. The approach represents a structural gravity model which is consistent with a large class of isomorphic models of international trade (see Arkolakis, Costinot and Rodríguez-Clare, 2012) such as the ones of Eaton and Kortum (2002), Anderson and van Wincoop (2003) or Bergstrand, Egger, and Larch (2013). At the same time, it entertains the merits of fixed country-pair effects estimation. Trade flows are specified as an exponential function of exporter-time, importer-time, and exporter-importer specific fixed effects using Poisson pseudo-maximum likelihood (PPML) estimation which is robust to heteroskedasticity of unknown form (Santos Silva and Tenreyro, 2006).[1] The framework imposes proper constraints that are consistent with both general equilibrium and a lower bound for trade costs, and we dub it a Constrained ANalysis Of VAriance model, CANOVA-PPML.

In an application to trade flows among 34 OECD countries between 2000 and 2002, we illustrate that the explanatory power of the model is excellent – considerably bet-

[1] Eaton and Kortum (2002), Baldwin and Taglioni (2006), Anderson and Yotov (2010, 2012), and Fally (2012) point to the fact that the fixed country effects in cross-section models (and, consequently, the fixed country-time effects in panel data models) do have a structural model interpretation if the data-generating process is the same as that of a structural gravity equation.

ter than the one of a model which relies on observable determinants of trade, mainly accruing to the inclusion of fixed country-pair effects – and how it can be used for comparative static analysis. Hence, the proposed framework closes the gap between structural modeling of trade flows and largely ad-hoc (without structural constraints and comparative static analysis) fixed effects estimation and quantification of the economic effects of trade barriers.

The next section discusses the empirical framework. Sections 3 and 4 illustrate the application of the approach in the aforementioned panel data-set regarding both estimation and counterfactual analysis. Section 5 outlines two straightforward extensions, and the last section provides a brief conclusion.

2 A structural CANOVA-PPML gravity model

In a large class of new trade models, aggregate bilateral demand (imports) of country i from country j at time s is determined by a gravity equation of the following generic form (see Arkolakis, Costinot, and Rodríguez-Clare, 2012):

$$X_{ijs} = \exp(\zeta_{js} + \beta \ln \tau_{ijs} + \mu_{is}) + u_{ijs}, \tag{2.1}$$

where ζ_{js} and μ_{is} are exporter-time and importer-time-specific factors,[2] τ_{ijs} are (iceberg) trade costs associated with shipping goods from j to i at time s, β is commonly

[2]Their interpretation depends on the underlying theoretical model. Exporter-time-specific factors are proportional to the level of technology in the source country (e.g., in Eaton and Kortum, 2002; Helpman, Melitz, and Rubinstein, 2008; or Bergstrand, Egger, and Larch, 2013), the number of exporters (see Krugman, 1980; or Bergstrand, Egger, and Larch, 2013), other factors capturing the size of the exporting country (see Anderson and van Wincoop, 2003), and to factor costs per efficiency unit in the exporting country. Importer-time-specific factors are proportional to the size of demand in the importer (aggregate factor endowments and average factor income) and to the ideal price index for the average household in the importing country in all aforementioned isomorphic model types.

referred to as the elasticity of trade (with respect to trade costs),[3] and u_{ijs} is a disturbance term. It turns out and evidence will be provided that τ_{ijs} can safely be modeled to be time-invariant such that $\tau_{ijs} \approx \tau_{ij}$ and $\beta \ln \tau_{ijs} \approx \delta_{ij}$ for all s, so that we can write:

$$X_{ijs} = \exp(\zeta_{js} + \delta_{ij} + \mu_{is}) + u_{ijs}. \tag{2.2}$$

If (2.2) could be log-transformed, its right-hand side would correspond to a three-way analysis of variance (ANOVA) with $\{is\}$, $\{js\}$, and $\{ij\}$-specific effects. With some chance of the error term being heteroskedastic and not log-additive as specified in (2.2), log-linearization leads to bias as indicated in Santos Silva and Tenreyro (2006). The Poisson pseudo-maximum likelihood estimator (PPML) can avoid this bias. However, general equilibrium constraints require the fixed effects in (2.2) to be estimated with specific constraints. In the large class of aforementioned models, general equilibrium implies that demand equates supply in all countries $\ell = 1, ..., N$ in the world economy. Let $E[\cdot]$ denote the expectation operator, then, as long as $E[u_{ijs}] = 0$ for all $\{ijs\}$, the following must hold:

$$E\left[\sum_{\ell=1}^{N} X_{i\ell s}\right] = E\left[\sum_{\ell=1}^{N} X_{\ell is}\right], \text{ or equivalently} \tag{2.3}$$

$$E\left[\sum_{\ell=1}^{N} \exp(\zeta_{\ell s} + \delta_{i\ell} + \mu_{is})\right] = E\left[\sum_{\ell=1}^{N} \exp(\zeta_{is} + \delta_{\ell i} + \mu_{\ell s})\right]. \tag{2.4}$$

A log-linear version of (2.2) with the constraint in (5.1) could be dubbed a constrained ANOVA-type – or CANOVA-type – estimator. Yet, aligned with the argument in Santos Silva and Tenreyro (2006), a CANOVA-PPML model is preferable and can

[3] The interpretation of β depends again on the underlying theoretical model. In Ricardian models of comparative advantage, it is a measure of the dispersion of technology across firms in the exporter, and in the new trade theory models based on the monopolistic competition it reflects the degree of competition and the elasticity of demand for (and substitution between) differentiated varieties of products contained in the aggregate.

easily be estimated, since inclusion of a large number of binary (dummy) variables in this exponential-family model does not lead to incidental parameter problems.

The structural constraint in (5.1) ensures that markets clear everywhere such that trade is multilaterally balanced and that the import demand structure is logistic, as is the case with constant-elasticity-of-substitution (CES) preferences. The latter is easy to show by merely transforming the constraint into

$$E\left[\mu_{is}\right] = \frac{E\left[\sum_{\ell=1}^{N} \exp(\zeta_{js} + \delta_{\ell i} + \mu_{\ell s})\right]}{E\left[\sum_{\ell=1}^{N} \exp(\zeta_{\ell s} + \delta_{i\ell})\right]}. \tag{2.5}$$

Hence, the importer-time fixed effect captures total import absorption (numerator) over the (CES) price index (denominator).

One also has to constrain δ_{ij} such that the corresponding elasticity-free trade cost parameters τ_{ijs} are of the iceberg-type trade cost form: $\tau_{ijs} \geq 1$ for all $\{ijs\}$. Since $\beta < 0$ and $\beta \ln \tau_{ijs} = \delta_{ij}$, the corresponding constraint is

$$\delta_{ij} \leq 1 \text{ for all } \{ij\}. \tag{2.6}$$

Constraints (5.1) and (2.6) apply for a large class of models bilateral trade models (see Arkolakis, Costinot, and Rodríguez-Clare, 2012; Arkolakis, Costinot, Donaldson, and Rodríguez-Clare, 2012).

3 Estimation

For illustration, we implement (2.2) subject to (5.1) and (2.6) using bilateral gross manufacturing import data among 34 OECD countries over the years 2000-2002. The data on gross import flows are from the OECD Structural Analysis Database. The overall sample includes $34\times(34-1)\times 3$ unique observations which are used to estimate $34\times 3\times 2$ exporter-time and importer-time specific fixed effects and $34\times(34-1)$ trade cost parameters up to a normalization.[4]

Let us first compare the model predictions of the unconstrained model (ANOVA-PPML) and the constrained model (CANOVA-PPML).[5] Clearly, the more the N (general equilibrium) constraints violate the data, the bigger is the difference between the two models, and the constrained model can never outperform the unconstrained one (by the Le Chatelier principle). In Figure 1 we plot the predictions for the two models and report the correlation coefficients between predictions and data. The figure suggests that either estimation strategy works extremely well, no matter whether the general equilibrium constraints are imposed or not. Provided the high explanatory power, there is little chance for omitted ($\{ijs\}$-specific) factors to result in an important endogeneity bias of estimates $z_{js}\equiv\widehat{\zeta}_{js}$, $d_{ij}\equiv\widehat{\delta}_{ij}$, or $m_{is}\equiv\widehat{\mu}_{is}$.[6] Moreover, the general equilibrium constraints lead to a loss of explanatory power of only 1.4 percentage points. Hence, even an annual imposition of those constraints works quite well for

[4]As the number of potential normalizations is infinity, we do not report the estimated *levels* of fixed effects but rather note that for comparative static analysis the relevant statistics are *relative changes*.

[5]In the ANOVA-PPML model, we implement constraint (2.6) which ensures comparability of the ANOVA-PPML and CANOVA-PPML models.

[6]By way of contrast, the difference between gravity models based on observable determinants of trade and fixed effects models is often quite large. For instance, the difference between the structural model based on observables and the fixed country effects estimator in the cross-sectional model of Anderson and van Wincoop (2003) amounts to about 23 percentage points (see Bergstrand, Egger, and Larch, 2013). The explained variance of a non-structural panel data model on bilateral trade flows with exporter-time effects, importer-time effects, exporter-importer effects, and observable time-variant determinants of bilateral trade in Baltagi, Egger, and Pfaffermayr (2003) exceeds the one of a comparable model with exporter-time effects, importer-time effects, and observable time-variant covariates by about 13 percentage points. This suggests that a large part of the variation in bilateral trade flow panels accrues to unmeasurable time-invariant factors. Finally, the correlation coefficient between the data and the model using log distance, an adjacency indicator, and a common language indicator times their parameters instead of d_{ij} is about 5 percentage points lower than that of the CANOVA-PPML model in Figure 1.

the data.

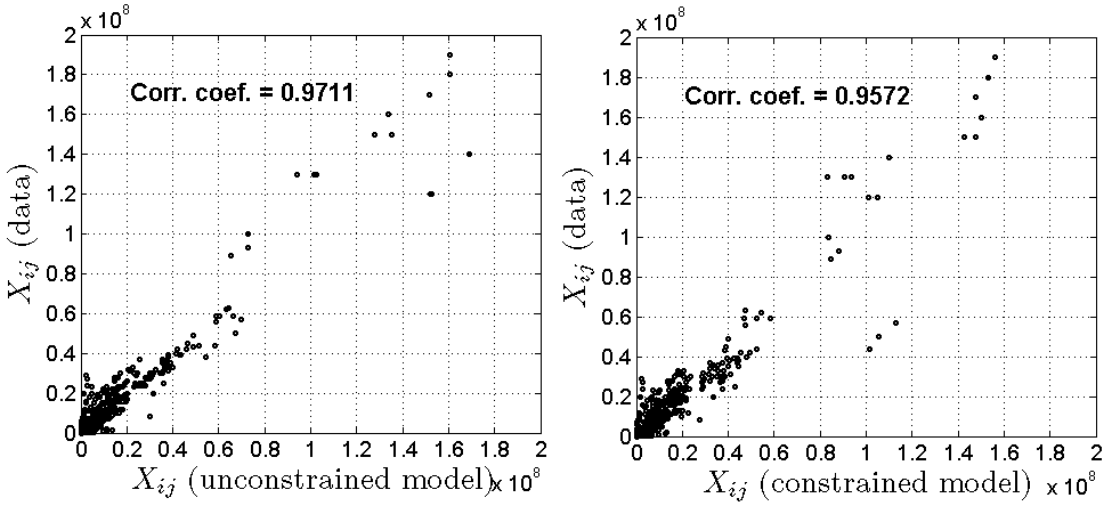

Figure 1: Estimation Results

To shed more light on how the constrained model differs from the unconstrained one in terms of fitting the data, we develop two further measures. Let ρ_j denote the correlation coefficient between the data and the model predictions for exporter j across all importers i and time periods s, and let ρ_i denote the respective correlation for importer i across all exporters and time periods. We report these statistics in Table 1.

Both ρ_i and ρ_j are high for most exporters and importers (except for Czech Republic and New Zealand) which suggests that the constrained model is not only a good predictor of bilateral trade flows on average but also for most individual countries in the data.

One of the central interests in estimating structural gravity equations is identification of the trade cost parameters. Of course, estimates δ_{ij} relate to trade costs τ_{ij} through trade cost elasticity β. While β is sometimes *estimated* (see, e.g., Eaton and Kortum, 2002; Costinot, Donaldson, and Komjuner, 2012; Egger and Nigai, 2012), it is *assumed* in most studies (see Anderson and van Wincoop, 2003; Alvarez and Lucas, 2007, Bal-

Table 1: Correlation Between Model and Data by Country

Country	Unconstrained		Constrained		Country	Unconstrained		Constrained	
	ρ_j	ρ_i	ρ_j	ρ_i		ρ_j	ρ_i	ρ_j	ρ_i
AUS	0.8128	0.553	0.8094	0.5031	JPN	0.9458	0.9798	0.9443	0.9799
AUT	0.9138	0.8845	0.9049	0.9207	KOR	0.701	0.8998	0.692	0.9021
BEL	0.9259	0.9272	0.9282	0.9057	LUX	0.978	0.9724	0.9822	0.9605
CAN	0.9985	0.9989	0.998	0.999	MEX	0.9322	0.9534	0.8731	0.9732
CHL	0.9582	0.9617	0.9391	0.9728	NLD	0.7735	0.8109	0.7603	0.8172
CZE	0.4093	0.5055	0.3868	0.6783	NZL	0.3304	0.3282	0.3006	0.3727
DNK	0.8835	0.8333	0.8727	0.8721	NOR	0.9887	0.9966	0.9926	0.9933
EST	0.9812	0.9849	0.9794	0.9759	POL	0.9324	0.9639	0.9284	0.958
FIN	0.8775	0.8131	0.868	0.8219	PRT	0.5501	0.7272	0.5582	0.7047
FRA	0.9508	0.9257	0.9533	0.9147	SVK	0.3261	0.3735	0.3078	0.3959
DEU	0.9658	0.9806	0.9699	0.9762	SVN	0.9435	0.9029	0.931	0.9422
GRC	0.815	0.8577	0.7422	0.8279	ESP	0.8561	0.8192	0.8744	0.7993
HUN	0.9751	0.963	0.9721	0.9545	SWE	0.8669	0.8088	0.865	0.7977
ISL	0.9788	0.9451	0.968	0.9406	CHE	0.9472	0.9538	0.9347	0.9705
IRL	0.586	0.8723	0.5602	0.8494	TUR	0.8877	0.8017	0.8686	0.7848
ISR	0.806	0.7342	0.7886	0.7938	GBR	0.9794	0.9493	0.9757	0.9436
ITA	0.8783	0.9166	0.8886	0.8969	USA	0.9768	0.9822	0.9888	0.9491

istreri and Hillberry, 2007; Balistreri, Hillberry, and Rutherford, 2011). The literature provides broad support for a range of $\beta \in [-2, -6]$ for the aggregate trade elasticity (see Anderson and van Wincoop, 2003). In the next figure, we report estimates $\widehat{\tau}_{ij}$ when assuming $\beta = -4$ and, as usually, $\tau_{ii} = 1$ so that $d_{ii} = 0$. Figure 2 displays $\widehat{\tau}_{ij}$ under this assumption by way of a 34×34 grid. The black squares along the diagonal reflect $\tau_{ii} = 1$, and the other cells suggest that $\widehat{\tau}_{ij} \in [1, 2.4)$ for all $i \neq j$.

Against the background of exorbitantly high trade costs estimated in many gravity equation applications (for a discussion, see Balistreri and Hillberry, 2006; or Allen, 2011), the findings in Figure 2 point to much more modest levels. The reason is that, unless the minimum level of trade costs is constrained to be unity, as is done throughout the literature on general equilibrium models of international trade, the average scale of productivity, country, size, and other country-specific factors, may not be distinguished from average trade cost levels. Then, at best the *variability* of trade costs but not their *level* is, in fact, identified. When constraining and identifying trade

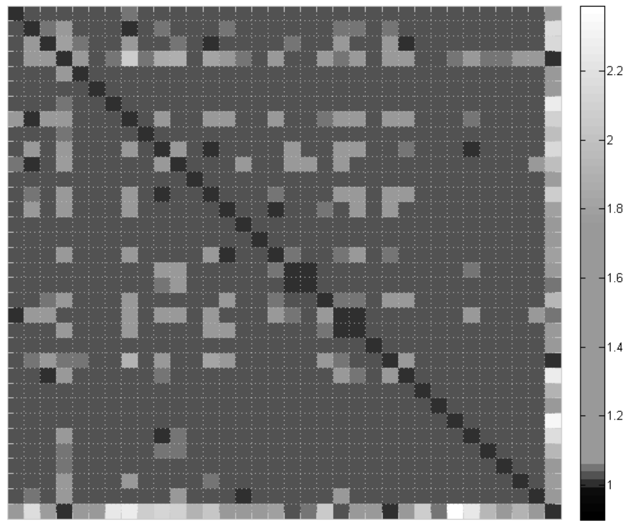

Figure 2: TRADE COSTS, τ_{ij}, FOR $\beta = -4$.

costs by d_{ij} as above, the average level of d_{ij} amounts to 1.09 and the standard deviation to 0.21, which is much smaller than often reported in unconstrained models. Moreover, an advantage of the present approach is the potential asymmetry whereby $\delta_{ij} \neq \delta_{ji}$ which is not achieved by parameterizations of δ_{ij} as a log-additive function of inherently symmetric variables (such as log distance and binary indicator variables capturing geographical, historical, institutional, or political similarity between countries). Finally, an advantage of the proposed framework is that it is immune against omission of – obviously highly relevant – unobservable variables beyond the typically considered time-invariant observable characteristics such as distance.

4 Counterfactual experiments

One of the merits of structural-form gravity models is the opportunity of assessing general equilibrium-consistent comparative static effects. In contrast, ad-hoc gravity models or fixed country(-time) effects estimates would focus on direct effects of trade costs, disregarding general equilibrium repercussions. In the context of the above model, this means that the parameters δ_{ij} represent only *direct effects* (semi-elasticities) of an elimination of trade costs on bilateral imports. Hence, changing d_{ij} exogenously to some counterfactual value, d'_{ij}, leads to *naïve* counterfactual trade flows of

$$X''_{ijs} = \exp(z_{js} + d'_{ij} + m_{is}), \tag{4.1}$$

which violates the aforementioned constraints. In general equilibrium, changing d_{ij} to d'_{ij} would inevitably change m_{is} to m'_{is} and z_{js} to z'_{js}. Hence, the general equilibrium-consistent response of trade flows, as opposed to (4.1), is

$$X'_{ijs} = \exp(z'_{js} + d'_{ij} + m'_{is}). \tag{4.2}$$

The structural constraints imposed in the estimation provide a mapping from d'_{ij} to the counterfactual values m'_{is} and z'_{js}. The counterfactual values of m'_{is} are

$$m'_{is} = \ln\left(\frac{\sum_{\ell=1}^{N}\exp\left(z'_{is} + d'_{\ell i} + m'_{\ell s}\right)}{\sum_{\ell=1}^{N}\exp\left(z'_{\ell s} + d'_{i\ell}\right)}\right) \tag{4.3}$$

and, provided that the change in z_{is} is proportional to the change in total absorption m_{is} for every $\{is\}$ (see Arkolakis, Costinot, and Rodríguez-Clare, 2012), z'_{is} is

$$z'_{is} = z_{is} + \frac{1}{\beta}\ln\left(\frac{\sum_{\ell=1}^{N}\exp\left(m'_{is} + z'_{\ell s} + d'_{\ell i}\right)}{\sum_{\ell=1}^{N}\exp\left(m_{is} + z_{\ell s} + d_{\ell i}\right)}\right). \tag{4.4}$$

Systems (4.3) and (4.4) contain $N \times 2$ equations that can be solved for the $N \times 2$ unknown s'_i and z'_i for every time period. As a numéraire, we may fix $\{m_{1s}, z_{1s}\} = \{m'_{1s}, z'_{1s}\}$.

For any generic variable v, use $\Delta v \equiv 100 \cdot (v'/v - 1)$ to denote the percentage change in v in a given year s and in response to some shock. Suppose we are interested in estimating changes in trade flows and welfare from a global 10% reduction in trade costs, τ_{ij}. In view of the changes in d_{ij}, choose:

$$d'_{ij} = \min\{\beta \ln(0.9) + d_{ij}, 0\}, \tag{4.5}$$

in year $s = 1$ (corresponding to 2000). Equipped with the counterfactual trade costs and the solutions for m'_{is} and z'_{js} we can calculate true counterfactual trade flows, X'_{ij} and compare them with naïve estimates, X''_{ij}. We consider the ratio between *naïve direct* and *general equilibrium consistent* effects. Let us use ϵ'_{ij} to denote that ratio between naïve (X''_{ij}) and consistent (X'_{ij}) predictions of counterfactual trade flows:

$$\epsilon_{ij} = \frac{X''_{ij}}{X'_{ij}}. \tag{4.6}$$

Figure 3 displays ϵ'_{ij} for $\beta = -4$ and the aforementioned shock in d_{ij}. In the figure, $\epsilon'_{ij} \in (0.84, 1.01)$, suggesting that, naïve counterfactual trade flows are biased by up to 10% in absolute value. Mostly, $\epsilon_{ij} < 0$, implying that naïve counterfactual predictions tend to be upward biased, which is consistent with the arguments in Anderson and van Wincoop (2003) in a cross-sectional, parameterized but otherwise isomorphic model.

Let us define two additional variables that reflect the measurement error of the naïve counterfactual trade flows:

$$\epsilon_j = \frac{1}{N}\sum_i \epsilon_{ij};\ \epsilon_i = \frac{1}{N}\sum_j \epsilon_{ij}. \tag{4.7}$$

The multipliers catch the average measurement error for each exporter and importer.

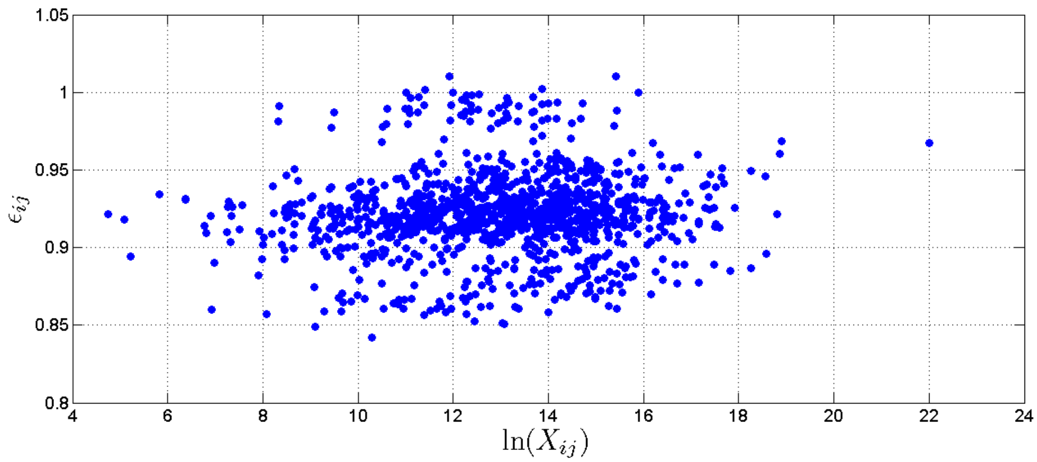

Figure 3: Measurement error in counterfactual trade predictions, ϵ_{ij}

They are reported in Table 2.

Having true changes in trade flows and β we can calculate welfare gains from trade liberalization as a change in the share of intra-trade flows as follows:

$$\Delta W_{is} = \left(\frac{\sum_{\ell} \exp(z'_{\ell s} + d'_{i\ell} + m'_{is})}{\exp(z'_{is} + m'_{is})} \frac{\exp(z_{is} + m_{is})}{\sum_{\ell} \exp(z_{\ell s} + d_{i\ell} + m_{is})} \right)^{\frac{1}{\beta}} . \tag{4.8}$$

We also report the counterfactual values of ΔW_{is} induced by a 10% reduction in trade barriers for different values of β.

Table 2: Results of the counterfactual experiments

	$\beta=-2$					$\beta=-4$					$\beta=-6$				
	Δz	Δm	ϵ_j	ϵ_i	ΔW	Δz	Δm	ϵ_j	ϵ_i	ΔW	Δz	Δm	ϵ_j	ϵ_i	ΔW
AUS	0.00	0.00	0.95	0.98	6.14	0.00	0.00	0.94	0.98	4.93	0.00	0.00	0.92	0.99	4.68
AUT	-0.39	-0.70	0.93	0.93	6.92	-0.26	-0.82	0.92	0.93	3.84	-0.18	-1.14	0.91	0.91	2.90
BEL	-0.28	-0.68	0.93	0.92	6.29	-0.21	-0.70	0.92	0.93	3.60	-0.18	-0.80	0.91	0.92	2.82
CAN	-0.13	-0.18	0.94	0.96	2.21	-0.10	-0.41	0.93	0.95	1.78	-0.08	-0.68	0.91	0.94	1.67
CHL	-0.55	-0.90	0.93	0.93	6.69	-0.41	-1.12	0.92	0.93	4.09	-0.35	-1.44	0.90	0.92	3.38
CZE	-0.68	-0.37	0.92	0.95	7.19	-0.71	0.17	0.90	0.99	4.96	-0.47	-0.82	0.89	0.94	4.07
DNK	-0.31	-0.78	0.93	0.93	5.83	-0.17	-0.97	0.93	0.92	3.05	-0.11	-1.26	0.91	0.91	2.26
EST	-0.75	-1.80	0.93	0.92	7.34	-0.65	-2.69	0.92	0.90	5.33	-0.62	-3.04	0.90	0.89	4.38
FIN	-0.32	-0.83	0.93	0.93	5.94	-0.19	-1.09	0.93	0.92	3.32	-0.13	-1.45	0.91	0.90	2.59
FRA	-0.29	-0.64	0.93	0.92	6.87	-0.20	-1.15	0.92	0.89	4.78	-0.16	-1.30	0.91	0.88	3.58
DEU	-0.24	-0.50	0.93	0.93	5.84	-0.23	-0.64	0.92	0.93	4.30	-0.17	-0.90	0.90	0.91	3.36
GRC	-0.39	-0.96	0.93	0.93	5.78	-0.24	-1.40	0.93	0.91	3.50	-0.18	-1.98	0.91	0.89	2.91
HUN	-0.34	-0.80	0.93	0.93	5.91	-0.24	-1.05	0.92	0.92	3.61	-0.21	-1.22	0.91	0.91	2.82
ISL	-1.05	-2.04	0.93	0.93	6.35	-0.80	-2.64	0.92	0.92	4.01	-0.71	-3.33	0.90	0.91	3.34
IRL	-0.42	-0.68	0.93	0.93	6.90	-0.29	-1.16	0.92	0.91	4.57	-0.24	-1.78	0.90	0.87	4.03
ISR	-0.41	-0.93	0.93	0.92	6.68	-0.31	-1.29	0.92	0.91	4.33	-0.28	-1.75	0.90	0.89	3.74
ITA	-0.27	-0.65	0.93	0.93	6.22	-0.21	-0.82	0.92	0.92	3.86	-0.18	-1.09	0.91	0.90	3.23
JPN	-0.48	-1.21	0.92	0.89	10.78	-0.29	-1.41	0.92	0.88	5.71	-0.18	-1.75	0.91	0.86	3.93
KOR	-0.57	-0.91	0.92	0.92	9.32	-0.35	-0.74	0.92	0.93	4.29	-0.20	-0.93	0.91	0.93	2.71
LUX	-0.42	-1.09	0.93	0.92	6.19	-0.27	-1.48	0.92	0.91	3.69	-0.21	-1.99	0.91	0.89	2.97
MEX	-0.39	-1.42	0.93	0.88	10.10	-0.26	-1.62	0.92	0.87	5.51	-0.18	-1.81	0.91	0.86	3.87
NLD	-0.41	-0.42	0.92	0.94	6.69	-0.36	-0.51	0.91	0.94	4.66	-0.34	-0.69	0.89	0.93	4.16
NZL	-0.90	-1.35	0.91	0.92	9.57	-0.72	-1.58	0.91	0.92	6.01	-0.45	-1.82	0.90	0.91	3.79
NOR	-0.34	-0.48	0.93	0.95	4.16	-0.15	-0.91	0.93	0.94	2.29	-0.07	-1.23	0.92	0.92	1.54
POL	-0.39	-0.65	0.93	0.94	6.05	-0.29	-0.61	0.92	0.94	3.37	-0.25	-0.59	0.90	0.95	2.56
PRT	-0.33	-0.73	0.93	0.93	5.53	-0.19	-1.04	0.93	0.92	3.19	-0.14	-1.46	0.91	0.90	2.57
SVK	-0.88	-1.27	0.91	0.92	9.49	-0.45	-2.82	0.92	0.86	6.04	-0.25	-3.13	0.91	0.85	3.87
SVN	-0.39	-0.90	0.93	0.93	5.34	-0.21	-1.15	0.93	0.93	2.78	-0.13	-1.54	0.91	0.91	2.05
ESP	-0.27	-0.76	0.93	0.92	6.15	-0.17	-0.96	0.93	0.91	3.53	-0.13	-1.14	0.91	0.90	2.66
SWE	-0.30	-0.82	0.93	0.92	6.34	-0.19	-1.02	0.93	0.91	3.57	-0.15	-1.29	0.91	0.90	2.80
CHE	-0.32	-0.64	0.93	0.93	5.93	-0.23	-0.85	0.92	0.92	3.68	-0.20	-1.14	0.91	0.91	3.09
TUR	-0.37	-0.85	0.93	0.93	6.19	-0.24	-1.21	0.92	0.91	3.76	-0.18	-1.71	0.91	0.89	3.10
GBR	-0.34	-0.63	0.93	0.92	7.31	-0.35	-0.82	0.91	0.92	5.65	-0.31	-0.98	0.90	0.91	4.54
USA	-0.02	-0.11	0.95	0.96	0.87	0.00	-0.30	0.94	0.95	0.84	0.00	-0.51	0.92	0.93	0.87

For some countries such as the United States the gains are moderate and, depending on the value of $beta = \{-2, -4, -6\}$, vary between 0.84% and 0.87%. For other countries, such as Korea, they are considerable and lie between 2.71% and 9.32%.

Generally relatively more remote countries such as Australia, Japan, Korea, and New Zealand gain more from gradual trade liberalization. The magnitude of the effects are plausible in view of the size of the change and the estimated trade cost matrix.

5 Variations on the theme

We can think of two particularly desirable modifications of the above approach. First of all, the general equilibrium (resource) constraint might be modified to account for trade imbalances along the lines of Dekle, Eaton, and Kortum (2007). As the previous approach, this would not require data beyond trade flows. With that modification, the general equilibrium constraints in (5.1) simply have to be modified to

$$E\left[\sum_{\ell=1}^{N} \exp(\zeta_{\ell s} + \delta_{i\ell} + \mu_{is})\right] = E\left[\sum_{\ell=1}^{N} \exp(\zeta_{is} + \delta_{\ell i} + \mu_{\ell s}) + D_{is}\right]. \qquad (5.1)$$

where $D_{is} \equiv E\left[\sum_{\ell=1}^{N} X_{i\ell s}\right] - E\left[\sum_{\ell=1}^{N} X_{\ell is}\right]$.

Second, even the gap between the CANOVA-PPML and ANOVA-PPML models could be eliminated without abandoning the structural interpretation. Then, the difference between the CANOVA-PPML and ANOVA-PPML would have to be minimized by solving for importer-specific trade costs, say, δ_i so that δ_{ij} above would have to be replaced by $\delta_{ij} + \delta_i$ (see Egger, Larch, and Staub, 2012).

6 Conclusion

This paper proposes a very simple procedure for estimating gravity equations consistent with economic theory and at minimal data requirements. The researcher only needs largely publicly available data on bilateral trade flows and fixed country-time and country-pair effects. The procedure is consistent with a large class of models of international trade. We show that direct effects of trade costs on trade in gravity equations are heavily biased measures of the general-equilibrium-consistent effects of trade costs. The approach advocated in this paper allows estimating and predicting in counterfactual equilibrium the change in international trade flows in response to observable and, to a large extent, to unobservable trade costs consistent with general equilibrium, while entertaining advantages of fixed effects estimation.

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