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Gravity *Redux*: Estimation of gravity-equation coefficients, elasticities of substitution, and general equilibrium comparative statics under asymmetric bilateral trade costs

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ABSTRACT

A large class of models with CES utility and iceberg trade costs are now known to generate isomorphic "gravity equations." Economic interpretations of these gravity equations vary in terms of two basic elements: the exporter's "mass" variable and the elasticity of trade with respect to true ad valorem "trade costs." In this paper, we offer three potential contributions. First, we formulate and estimate a structural gravity equation based on the standard Krugman model of monopolistic competition and increasing returns. In the context of this model, a key parameter, the elasticity of substitution in consumption (σ), can be estimated precisely – even without observable true ad valorem trade-cost measures – using exporter's population and observable variables that influence trade costs. Second, in the empirical context of the well-known McCallum Canadian–U.S. "border puzzle," our approach – allowing estimation of σ – yields considerably different general equilibrium comparative static trade-flow and economic welfare effects than those in an Armington endowment economy and assumed values of σ. Moreover, our predicted trade flows and GDPs are highly correlated with their respective observed values in the case of bilaterally symmetric *or* asymmetric Canadian–U.S. border effects. Third, a Monte Carlo analysis confirms unbiased and precise estimates of all coefficients, the elasticity of substitution, and comparative statics using our approach.

1. Introduction

For half a century, the "gravity equation" has been used to estimate econometrically the ex post partial (or direct) effects of economic integration agreements, national borders, currency unions, language, and other measures of trade costs on bilateral international trade flows (cf., Anderson, 2011 and Bergstrand and Egger, 2011 for recent surveys). While two early formal theoretical foundations for the gravity equation with trade costs – first Anderson (1979) and later Bergstrand (1985) – addressed the role of "multilateral prices," Anderson and van Wincoop (2003) refined the theoretical foundations for the gravity equation to emphasize the importance of accounting properly for the endogeneity of prices in a structural gravity model. Eaton and Kortum (2002), Melitz (2003), Helpman et al. (2008), and Chaney (2008) refined the theoretical foundations further for firm heterogeneity in productivity and zero trade flows. As Eaton and Kortum (2002) and Arkolakis et al. (2012) note, there is a large class of models with constant-elasticity-of-substitution (CES) preferences, iceberg trade costs, and complete specialization that generate isomorphic gravity equations.

In Anderson and van Wincoop (2003), or AvW, a complete derivation of a standard Armington ("conditional," in AvW terms) general equilibrium endowment-economy model of bilateral trade in a multi-region ($N>2$) setting with one good per region and iceberg trade costs suggests that traditional cross-section empirical gravity equations have been misspecified owing to the omission of theoretically motivated nonlinear multilateral price terms for exporting and importing regions. Their model yields the bilateral trade "structural" gravity model allowing asymmetric bilateral trade costs (ABTC):

$$X_{ij} = \frac{Y_i Y_j}{Y_W} \frac{t_{ij}^{1-\sigma}}{\Pi_i^{1-\sigma} P_j^{1-\sigma}}, \quad (1)$$

where $\Pi_i^{1-\sigma} = \sum_{j=1}^{N} \frac{Y_j}{Y_W} \frac{t_{ij}^{1-\sigma}}{P_j^{1-\sigma}}, \; P_j^{1-\sigma} = \sum_{i=1}^{N} \frac{Y_i}{Y_W} \frac{t_{ij}^{1-\sigma}}{\Pi_i^{1-\sigma}},$

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where X_{ij} is the nominal trade flow from region i to region j, Y_i (Y_j) is the nominal GDP in i (j), Y_W is world GDP, t_{ij} is one plus the iceberg trade costs (the latter expressed as an ad valorem rate) on goods exported from i to j, and σ is the elasticity of substitution in consumption. In the special case of symmetric bilateral trade costs (SBTC), $t_{ij} = t_{ij}$, the system of Eq. (1) reduces to:

$$X_{ij} = \frac{Y_i Y_j}{Y_W} \frac{t_{ij}^{1-\sigma}}{P_i^{1-\sigma} P_j^{1-\sigma}}, \text{ where } P_i^{1-\sigma} = \sum_{j=1}^{N} \frac{Y_j}{Y_W} \frac{t_{ij}^{1-\sigma}}{P_j^{1-\sigma}}. \quad (2)$$

Owing to the nonlinearities in both sets of structural relationships, AvW employ a nonlinear least squares (NLS) program for estimation, focusing on Eq. (2) with SBTC. In the absence of observable measures of t_{ij}, AvW assume $t_{ij}^{1-\sigma} = d_{ij}^{(1-\sigma)\rho} e^{[(1-\sigma) lnb_{US,\ CA}]\text{Border}_{ij}}$ where d_{ij} is bilateral distance, Border_{ij} is a dummy variable with a value of 1 (0) if the two regions are separated by a national border, σ, ρ, and $lnb_{US,\ CA}$ are unknown parameters, and e is the natural log base. Consequently, the system of equations does not permit identification of σ separately from ρ and $lnb_{US,\ CA}$.[1] Hence, for general equilibrium comparative static estimates, they *assume* values of σ. Moreover, all estimation of parameters and calculation of comparative statics were conducted under the assumption of SBTC, even though many bilateral trade costs are asymmetric. For instance, based on bilateral tariff data from the Global Trade Analysis Project (GTAP) on 67 countries in 2001, there is a large heterogeneity bilaterally in tariff rates. Fifty-eight percent of the bilateral tariff rates are asymmetric; moreover, the asymmetry can be as large as 150%.[2]

Eaton and Kortum (2002), or EK, introduced an alternative Ricardian framework to generate a structural gravity equation where the key parameter, θ, governs the heterogeneity in firms' productivities (or comparative advantages):

$$X_{ij} = \frac{T_i Y_j \left(w_i t_{ij}\right)^{-\theta}}{\sum_{k=1}^{N} T_k \left(w_k t_{kj}\right)^{-\theta}}, \quad (3)$$

where T_i is an index of country i's "state of technology" and w_i is labor's wage rate.[3] While preferences are also modeled using CES utility, the elasticity of substitution in consumption (σ) does not have a role in determining equilibrium bilateral trade flows. The structure of the model implies that the key parameter for estimation (and subsequently for comparative statics) is the supply-side measure of firm heterogeneity (θ). To identify θ, EK used two alternative approaches, one using retail price data and another using wage data.[4]

However, as Arkolakis et al. (2012) note, the perfect competition models in AvW and EK and the monopolistic competition models in Krugman (1980) and Melitz (2003) are all in a broad class of models sharing Dixit–Stiglitz preferences, one factor of production, linear cost functions, complete specialization, and iceberg trade costs. Arkolakis et al. (2012) show that if three "macro-level" restrictions hold, then all four models will share a common estimator of the gains from trade — which depends only on the import-penetration ratio and a gravity-equation-based estimate of the "trade-cost" elasticity of trade flows (of which σ is a measure of in many models).

In this paper, we first formulate a structural gravity equation based on Krugman (1980) monopolistic competition and increasing returns to scale (MC-IR) model as an alternative framework to AvW and EK for estimating gravity-equation coefficients, the elasticity of substitution in consumption (σ), and general equilibrium comparative statics, allowing ABTC.[5] We show in the context of this model that σ (the key parameter for welfare analysis) can be identified *precisely* — even without observable ad valorem trade-cost measures. The reason is that the exporter's absolute factor endowment – related to the number of varieties produced – helps identify (or "pin down") individual exporters' price levels (p_i), which allows identification of σ (not possible in the AvW framework). In reality, unlike in the AvW framework with one good per region, most regions produce a variety of products and evidence suggests that the *number* of varieties/producers – that is, the extensive margin of varieties produced per region – is related to the absolute factor endowment size of the region (cf., Bernard et al., 2009).[6]

Second, in the empirical context of the well-known "McCallum border puzzle," we apply our approach for estimating gravity-equation coefficients, the elasticity of substitution, and general equilibrium comparative statics. Since our *estimated* σ differs from the one assumed in AvW, our general equilibrium comparative statics differ significantly from those in AvW. However, our estimate of approximately 7 is in the middle of the range of typical estimates for σ of 5–10 discussed in Anderson and van Wincoop (2004).

Third, we use a Monte Carlo analysis to confirm precise and unbiased estimates of all coefficients, the elasticity of substitution, and general equilibrium comparative statics using our approach, even in small samples. We also demonstrate using this analysis that the comparative static effects on trade flows of a given trade-cost change can be *very sensitive* to the elasticity of substitution, with such effects for $\sigma = 10$ more than 40 times those for $\sigma = 3$. We show that our approach and the AvW approach under ABTC can also be used for general equilibrium comparative statics for *real* economic variables, such as economic welfare. However, these results are very sensitive – even qualitatively – to σ, providing further motivation for finding a technique that identifies σ precisely.

The remainder of this paper is as follows. Section 2 presents the well-known Krugman MC-IR model to derive a structural gravity model that allows estimation of the elasticity of substitution (given consistently estimated gravity equation parameters) and of comparative static effects. Section 3 provides an empirical analysis of our approach and compares it to the results from other approaches, including AvW, in the well-known context of the McCallum Canadian–U.S. border puzzle. Section 4 presents Monte Carlo results demonstrating – in the absence of specification and measurement error – that we can obtain precise and unbiased estimates of the elasticity of substitution and of comparative statics using our approach. Section 5 concludes.

[1] Of course, this issue generalizes for any number of determinants of $t_{ij}^{1-\sigma}$.

[2] Balistreri and Hillberry (2007) first showed that allowing for asymmetric bilateral trade costs influences the results of estimating the Canadian–U.S. "border effect."

[3] For conciseness, we ignore intermediate goods in this specification, a component of the original EK model.

[4] In one approach, they employed cross-country disaggregate retail price level data to approximate bilateral ad valorem trade costs (t_{ij}). Assuming commodity price arbitrage, the maximum difference between two countries' prices for similar goods bounds ad valorem bilateral trade costs. Second, they used wage rate data (and alternatively instruments for w_i) to estimate θ. Using wage rate data (wage instruments), EK found an estimate for θ of 2.86 (3.60). Using the disaggregated price data and the commodity-price-arbitrage condition, EK found estimates of θ ranging between 2.44 and 12.86 depending upon OLS or two-stage least squares estimation.

[5] As noted above, AvW could only assume values for σ. Waugh (2007) also notes the importance of asymmetric bilateral trade costs for explaining observed bilateral trade flow patterns and relative price and real per capita income differences between countries.

[6] An earlier related paper to ours is Lai and Trefler (2002), which examines using panel data the MC-IR model. With regard to model specification issues, Lai and Trefler find that the MC-IR model works well, explaining about 78% of the variation in bilateral (aggregate manufacturing) trade flows and they also use their model to estimate welfare effects of tariff liberalizations. Our approach also has parallels to Redding and Venables (2004), where the authors derive a gravity equation based upon the MC-IR model. They estimate the model and the predicted trade flows are then used to construct market-access and supply-access variables, which are then used (as generated regressors) in a wage (per capita income) equation to explain sources of wage variation. They do not address comparative statics, estimation of any nonlinear price terms, nor estimation of the elasticity of substitution.