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Bonus vetus OLS: A simple method for approximating international trade-cost effects using the gravity equation[☆]

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ABSTRACT

Using a Taylor-series expansion, we solve for a simple reduced-form gravity equation revealing a transparent theoretical relationship among bilateral trade flows, incomes, and trade costs, based upon the model in Anderson and van Wincoop [Anderson, James E., and van Wincoop, Eric. "Gravity with Gravitas: A Solution to the Border Puzzle." American Economic Review 93, no. 1 (March 2003): 170–192.]. Monte Carlo results support that virtually identical coefficient estimates are obtained easily by estimating the reduced-form gravity equation including theoretically-motivated exogenous multilateral resistance terms. We show our methodology generalizes to many settings and delineate the economic conditions under which our approach works well for computing comparative statics and under which it does not.

1. Introduction

For nearly a half century, the gravity equation has been used to explain econometrically the *ex post* effects of economic integration agreements, national borders, currency unions, immigrant stocks, language, and other measures of "trade costs" on bilateral trade flows. Until recently, researchers typically focused on a simple specification akin to Newton's Law of Gravity, whereby the bilateral trade flow from region i to region j was a multiplicative (or log-linear) function of the two countries' gross domestic products (GDPs), their bilateral distance, and an array of bilateral dummy variables assumed to reflect the bilateral trade costs between that pair of regions; we denote this the "traditional" gravity equation.

However, the traditional gravity equation has come under scrutiny, partly because it ignores that the volume of trade from region i to region j should be influenced by trade costs between regions i and j *relative* to those of the rest-of-the-world (ROW), and the economic sizes of the ROW's regions (and prices of their goods) matter as well. 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. Two major conclusions surfaced from the seminal Anderson and van Wincoop (henceforth, A-vW) study, "Gravity with *Gravitas*." First, traditional cross-section empirical gravity equations have been misspecified owing to the omission of theoretically-motivated endogenous multilateral (price) resistance terms for exporting and importing regions. Second, to estimate properly the general equilibrium comparative statics of a national border or an EIA, one needs to estimate these multilateral resistance (MR) terms for any two regions with *and* without a border, in a manner consistent with theory. Due to the nonlinearity of the structural relationships, A-vW applied a custom nonlinear least squares (NLS) program to account for the endogeneity of prices and estimate the general equilibrium comparative statics.

Another — and computationally less taxing — approach to estimate unbiased gravity equation coefficients, which also acknowledges the influence of theoretically-motivated MR terms, is to use region-

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specific fixed effects, as noted by A-vW, Eaton and Kortum (2002), and Feenstra (2004). An additional benefit is that this method avoids the measurement error associated with measuring regions' "internal distances" for the MR variables. Indeed, van Wincoop himself — and nearly every gravity equation study since A-vW — has employed this simpler technique of fixed effects for determining gravity-equation parameter estimates, cf., Rose and van Wincoop (2001) and Baier and Bergstrand (2007a). Yet, without the structural system of nonlinear equations, one still cannot generate region- or pair-specific general equilibrium (GE) comparative statics; fixed effects estimation precludes estimating MR terms with *and* without EIAs. Empirical researchers can use fixed effects to obtain the key gravity-equation parameter estimates, and then simply construct a system of nonlinear equations to estimate multilateral price terms with and without the "border." But they don't.

Consequently, the empirical researcher faces a tradeoff. A customized NLS approach can potentially generate consistent, efficient estimates of gravity-equation coefficients *and* comparative statics, but it is computationally burdensome relative to ordinary least squares (OLS) and subject to measurement error associated with internal distance measures. Fixed-effects estimation uses OLS and avoids internal distance measurement error for MR terms, but one cannot retrieve the multilateral price terms necessary to generate quantitative comparative-static effects without also employing the structural system of equations. Is there a third way to estimate gravity equation parameters using *exogenous* measures of multilateral resistance and "good old" ("*bonus vetus*") OLS and/or compute region-specific resistance terms that can be used to approximate MR terms for comparative statics or other purposes (to be discussed later) without using a nonlinear solver? This paper suggests a method that may be useful.

Following some background, this paper has three major parts: theory, estimation, and comparative statics. First, we suggest a method for "approximating" the MR terms based upon theory. We use a simple first-order log-linear Taylor-series expansion of the MR terms in the A-vW system of equations to motivate a reduced-form gravity equation that includes theoretically-motivated exogenous MR terms that can be estimated potentially using OLS. However — unlike fixed-effects estimation — this method can *also* generate theoretically-motivated general equilibrium comparative statics without using a system of nonlinear equations or assuming symmetric bilateral trade costs.

Second, we show that our first-order log-linear approximation method provides *virtually identical* coefficient estimates for gravity-equation parameters to those in A-vW. For tractability, we apply our technique first to actual trade flows using the same context and Canadian–U.S. data sets as used by McCallum (1995), A-vW, and Feenstra (2004). However, the insights of our paper have the potential to be used in numerous contexts, especially estimation of the effects of tariff reductions and free trade agreements on world trade flows — the most common usage of the gravity equation in trade. Using Monte Carlo techniques, we show that the linear approximation approach works in the context of regional (intra-continental) and world (intra- and inter-continental) trade flows.

Third, we demonstrate the economic conditions under which our approximation method works well to calculate comparative-static effects of key trade-cost variables… and when it does not. We compare the comparative statics generated using our approach versus those using A-vW's approach both for the Canadian–U.S. context and for world trade flows using Monte Carlo simulations. We find that the largest comparative static changes in multilateral price terms (and largest approximation errors) tend to be among — not just small GDP-sized economies (and consequently those with large trading partners) as emphasized in A-vW — but small countries that are *physically close*. Using a fixed-point iterative matrix manipulation, the approximation errors can be eliminated using an $N \times N$ matrix of GDP shares *relative to* bilateral distances, that is, measures of economic "density." Since our approximation method can generate MR terms even when trade costs are bilaterally asymmetric, our method can yield lower average absolute biases of comparative statics than the A-vW method (which only addresses average border barriers under asymmetry).

The remainder of the paper is as follows. Section 2 reviews the A-vW analysis. Section 3 uses a first-order log-linear Taylor-series expansion to motivate a simple reduced-form gravity equation. In Section 4, we apply our estimation technique to the McCallum–A-vW–Feenstra data set and compare our coefficient estimates to these papers' findings. Section 5 examines the economic conditions under which our approach approximates the comparative statics of trade-cost changes well and under which it does not. Section 6 concludes.

2. Background: the gravity equation and prices

2.1. The A-vW theoretical model

To understand the context, we initially describe a set of assumptions to derive a gravity equation; for analytical details, see A-vW (2003). First, assume a world endowment economy with N regions and N (aggregate) goods, each good differentiated by origin. Second, assume consumers in each region j have identical constant-elasticity-of-substitution (CES) preferences. Maximizing utility subject to a budget constraint yields a set of first-order conditions that can be solved for the demand for the nominal bilateral trade flow from i to j (X_{ij}):

$$X_{ij} = \left(\frac{p_i t_{ij}}{P_j}\right)^{1-\sigma} Y_j \tag{1}$$

where p_i is the exporter's price of region i's good, t_{ij} is the gross trade cost (one plus the *ad valorem* trade cost) associated with exports from i to j, Y_j is GDP of country j, and P_j is the CES price index given by:

$$P_j = \left[\sum_{i=1}^{N} (p_i t_{ij})^{1-\sigma}\right]^{1/(1-\sigma)}. \tag{2}$$

A third assumption of market-clearing and some algebraic manipulation yields:

$$X_{ij} = \left(\frac{Y_i Y_j}{Y^T}\right)\left(\frac{t_{ij}}{\Pi_i P_j}\right)^{1-\sigma} \tag{3}$$

where

$$\Pi_i = \left[\sum_{j=1}^{N} \left(\theta_j / t_{ij}^{\sigma-1}\right) P_j^{\sigma-1}\right]^{1/(1-\sigma)} \tag{4}$$

$$P_j = \left[\sum_{i=1}^{N} \left(\theta_i / t_{ij}^{\sigma-1}\right) \Pi_i^{\sigma-1}\right]^{1/(1-\sigma)} \tag{5}$$

Y^T denotes total income of all regions, which is constant across region pairs, and θ_i (θ_j) denotes Y_i / Y^T (Y_j / Y^T). It will be useful now to define the term "economic density." For i, the bilateral "economic density" of a trading partner j is the amount of economic activity in j relative to the cost of trade between i and j, or $\theta_j / t_{ij}^{\sigma-1}$.

To solve this system of equations, A-vW employed a strong fourth assumption: trade costs are symmetric bilaterally, implying $t_{ij} = t_{ji}$. Under this fourth assumption, their model simplifies to a system of N^2 equations in $N(N-1)$ endogenous trade flows and N endogenous price terms (P).

2.2. The A-vW econometric model

As is common to this literature, for an econometric model we assume the log of the observed trade flow ($\ln \boldsymbol{X}_{ij}$) is equal to the log of the true trade flow ($\ln X_{ij}$) plus a log-normally distributed error term (ε_{ij}). Y_i can feasibly be represented empirically by observable $\mathbf{GDP}_i$. However, the world is not so generous as to provide observable measures of bilateral