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Structural gravity and fixed effects☆

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ABSTRACT

The gravity equation for trade flows is one of the most successful empirical models in economics and has long played a central role in the trade literature (Anderson, 2011). Different approaches to estimate the gravity equation, i.e. reduced-form or more structural, have been proposed. This paper examines the role of adding-up constraints as the key difference between structural gravity with "multilateral resistance" indexes and reduced-form gravity with simple fixed effects by exporter and importer. In particular, estimating gravity equations using the Poisson pseudo-maximum-likelihood estimator (Poisson PML) with fixed effects automatically satisfies these constraints and is consistent with the introduction of "multilateral resistance" indexes as in Anderson and van Wincoop (2003).

1. Introduction

The gravity equation is one of the most successful empirical models in economics and has been the focus of a very extensive literature in international trade (Anderson, 2011). The very good fit of the gravity equation for bilateral trade flows has long been recognized since Tinbergen (1962) and the many papers that followed.[1]

Various ways to specify and estimate the gravity equation have been proposed (see Feenstra, 2004; Head and Mayer, 2014). Specifications vary broadly along two dimensions. A first dimension concerns the error term. The second is the degree of model structure that is imposed on the estimation. Among the estimation approaches available, one possibility is to use the Poisson pseudo-maximum likelihood method (Poisson-PML). Santos Silva and Tenreyro (2006) show that Poisson-PML consistently estimates the gravity equation for trade and is robust to different patterns of heteroskedasticity and measurement error, which makes it preferable to alternative procedures such as ordinary least squares (using the log of trade flows) or non-linear least squares (in levels).[2]

There are also different trends in the specification of supply-side and demand-side effects in the gravity equation. Early papers have simply used total (multilateral) expenditures and total output for supply- and demand-side terms. It has been recognized, however, that adjustments are necessary to account for differences in market thickness across destinations (captured by the "inward multilateral-resistance index" in Anderson and van Wincoop, 2003) and source countries (captured by the "outward multilateral resistance index"). There are now two main ways to account for these adjustments. A set of papers introduces exporter and importer fixed effects to capture both market-size effects and multilateral-resistance indexes in a simple way (e.g. Harrigan, 1996; Redding and Venables, 2004). Another trend instead imposes more structure on the gravity equation. This approach has been put forward by Anderson and van Wincoop (2003), Anderson and Yotov (2010), and Balistreri and Hillberry (2007), with some variations in the restrictions imposed on the demand side (e.g., Fieler 2011) or supply side (e.g., Costinot, Donaldson and Komunjer, 2012).[3]

In this paper, I show that estimating gravity with Poisson PML and fixed effects is consistent with the equilibrium constraints imposed by more structural approaches such as those of Anderson and van

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[1] Note that most gravity equation estimates focus on the cross-section. Lai and Trefler (2002) is one of the few exceptions; they find that the gravity equation framework does not perform as well in time series.

[2] Poisson-PML is also consistent with the presence of zero bilateral trade flows, which are highly prevalent in disaggregated data. An alternative method by Helpman, Melitz and Rubinstein (2008) involves a 2-step estimation to structurally account for zeros.

[3] A growing literature also uses the MPEC approach, as in Balistreri et al (2011).

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Wincoop (2003) and Anderson and Yotov (2010). In particular, the estimated fixed effects in the Poisson PML specification are consistent with the definition of outward and inward multilateral resistance indexes and the equilibrium constraints that they need to satisfy. Therefore, gravity regressions with fixed effects and Poisson PML can be used as a simple tool to solve the estimation problem raised by Anderson and van Wincoop (2003).

More generally, the constraints imposed on multilateral-resistance indexes in the structural-gravity framework are equivalent to imposing adding-up constraints on the sum of trade flows for each source country and each destination. This result is valid for any estimator. However, when the Poisson-PML estimator is used, these constraints are automatically satisfied as long as we have exporter and importer fixed effects and consistent data. This adding-up property is specific to Poisson-PML regressions and could also be useful for other applications where we want to constrain the sum of fitted values to be fixed, because other estimators do not automatically satisfy adding-up constraints.[4]

In the last section, I estimate gravity equations and provide quantitative examples to illustrate these points. First, these results imply that the test of structural gravity performed by Anderson and Yotov (2010) is bound to support structural gravity when Poisson-PML is used. I verify this assertion using consistent data where outward trade flows sum up to output and inward trade flows sum up to expenditures. Secondly, I find large deviations between fitted output and observed output when gravity is estimated with importer and exporter fixed effects, especially with ordinary least squares (OLS) and Gamma-PML estimators. I also find large differences between multilateral-resistance indexes depending on whether they are constructed from importer or exporter fixed effects, unless we impose additional constraints on these indexes. Thirdly, there are systematic biases depending on market size. With OLS and Gamma-PML, the sum of fitted trade flows tends to be larger than observed output for large countries and smaller than observed output for small countries. This points to undesirable properties of OLS and Gamma-PML when no constraints on multilateral-resistance indexes are imposed.

2. The gravity model

A wide range of trade models generate relationships in bilateral trade flows that can be expressed by the following set of equations. For each exporter i and importer j, trade flows X_{ij} should satisfy:

$$X_{ij} = \frac{Y_i}{\Pi_i^{-\theta}} \;.\; D_{ij}^{-\theta} \;.\; \frac{E_j}{P_j^{-\theta}}. \tag{1}$$

In this equation, Y_i refers to total output in country i; E_j refers to total expenditure in country j; D_{ij} captures trade costs from i to j; and the parameter θ reflects the elasticity of trade flows to trade costs, which may have different structural interpretations depending on the model, as described below. Finally, the terms $P_j^{-\theta}$ and $\Pi_i^{-\theta}$ are called "multilateral resistance" indexes by Anderson and van Wincoop (respectively "inward" and "outward" resistance indexes). These two resistance terms should satisfy the following constraints for consistency, which define the "structural gravity" framework (Anderson, 2011).

Definition. "*Structural gravity*": *The patterns of trade flows X_{ij} are consistent with the "structural gravity" framework if they satisfy Eq. (1) with the following two constraints on multilateral-resistance terms P_j and Π_i:*

$$P_j^{-\theta} = \sum_i \frac{Y_i D_{ij}^{-\theta}}{\Pi_i^{-\theta}} \tag{2}$$

$$\Pi_i^{-\theta} = \sum_j \frac{E_j D_{ij}^{-\theta}}{P_j^{-\theta}}. \tag{3}$$

These equations define P_j and Π_i. Given output Y_i, expenditures E_j and trade costs $D_{ij}^{-\theta}$, the solution in $P_j^{-\theta}$ and $\Pi_i^{-\theta}$ to this system of two equations is unique, up to a constant (the proof of uniqueness is provided with Lemma 3 in Appendix A). As noted by Anderson and Yotov (2010), when $P_j^{-\theta}$ and $\Pi_i^{-\theta}$ satisfy Eqs. (2) and (3), $\lambda P_j^{-\theta}$ and $\Pi_i^{-\theta}/\lambda$ are also solutions, for any number $\lambda > 0$. This indeterminacy calls for a normalization; we thus impose $P_0 = 1$ for a benchmark importer $j = 0$. These equations can also be defined at the industry or product level. For convenience, I do not add industry subscripts but all results in the paper hold within each industry (as in Anderson and Yotov, 2010 and 2012).

This system of equations can be derived from various types of models. It is consistent with models based on Armington (1969) and Krugman (1980) with a constant elasticity of substitution in consumer preferences (Anderson and Van Wincoop, 2003; Redding and Venables, 2004, Fally, Paillacar and Terra, 2010, among many others). In these models, $\theta + 1$ corresponds to the elasticity of substitution. Models based on Melitz (2003), such as Chaney (2008), can also generate gravity equations, as above. In this case, the equivalent of θ would be the coefficient of the Pareto distribution of firm productivity; the coefficient is inversely related to productivity dispersion. As shown by Eaton and Kortum (2002), Ricardian models of trade are also fully consistent with gravity. In this case, the trade-cost elasticity θ corresponds to one of the coefficients of the Frechet distribution of productivity across product varieties (again, the coefficient is inversely related to productivity dispersion).[5] In all of the above-mentioned models, the inward multilateral resistance index $P_j^{-\theta}$ can be expressed as a function of the price index in the importing market. In turn, $\Pi_i^{-\theta}$ captures the degree of competition faced by exporter i.

Various theoretical features have been used to generate structural gravity equations, including a constant elasticity of substitution, Pareto distributions of productivity (Chaney, 2008, Costinot et al., 2011) and Frechet distributions (Eaton and Kortum, 2002). The key ingredient is that trade flows can be written as a product of an exporter term, an importer term and a term reflecting trade costs (separability condition). Another key ingredient is a consistent definition of output and expenditures.

Formally, Head and Mayer (2014) define "general gravity" when trade flows can be written as $X_{ij} = exp[e_i - \theta log D_{ij} + m_j]$ where e_i is invariant across importers and m_j is invariant across importers j. "General gravity" is in fact equivalent to "structural gravity" when output equals the sum of outward trade $Y_i = \sum_j X_{ij}$ and expenditures equal the sum of inward trade $E_j = \sum_i X_{ij}$. When trade satisfies the "general gravity" condition, we can re-express trade as in Eq. (1) with a unique set of inward and outward multilateral-resistance indexes satisfying Eqs. (2) and (3). This is shown formally in Lemma 3 in Appendix A. This equivalence has important empirical implications, which are illustrated with Lemma 1A and 1B in the next section.

3. Gravity with fixed effects

To estimate Eq. (1), there are broadly two approaches which differ in the treatment of exporter terms $\frac{Y_i}{\Pi_i^{-\theta}}$ and importer terms $\frac{E_j}{P_j^{-\theta}}$.

A first approach, the reduced-form, simply introduces exporter and importer fixed effects e_i and m_j without imposing any constraints on these terms. This approach ignores the structure proposed by Eqs. (2) and (3). The estimated equation can then be written:

$$X_{ij} = exp\left[e_i - \theta log D_{ij} + m_j\right] . \varepsilon_{ij} \tag{4}$$

[4] For instance, Poisson-PML could be useful in consumption choice models where the sum of expenditures is fixed for given subsets of observations.

[5] Gravity equations can also be motivated by Heckscher–Ohlin and specific-factor models (see Evenett and Keller, 2002).