# *Structural* Gravity Estimation & Agriculture*

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**Abstract**

Recently, discussion about the appropriate estimation of gravity trade models has started in agriculture. Here, we are going to review recent developments in the literature. It appears that fixed effects Poisson Pseudo Maximum Likelihood is not only the only consistent estimator [Santos Silva and Tenreyro, 2006] but also it already allows for a structural fit [Fally, 2012]. Fixed effects in conjunction with the adding-up property of Poisson Pseudo Maximum Likelihood - which has been so far neglegted - can be harnessed to directly deduce multilateral resistance indexes (i.e. general equilibrium effects) from reduced-form estimation. This innovation made by Fally will ease comparative statics and incidence analysis, making Poisson Pseudo Maximum Likelihood even more preferable in practice.

**Keywords:** Gravity Estimation, Poisson Pseudo Maximum Likelihood, Adding-up, Structural Fit

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## 1 Introduction

Appropriate estimation techniques of gravity trade models have been discussed recently in agricultural economics.[1][2] Agriculture in particular is a special case as one focuses on a micro sector and thus on disaggregate trade flows. Here, one has to deal with excess zeros and heteroskedasticity. Different estimators have been proposed (i.e. zero-inflated count data models) [Burger et al., 2009], however all of them have their disadvantages, such as suffering from in particular model misspecification and scale dependence [Prehn and Brümmer, 2011]. If one does not explicitly focus on the extensive and intensive margin of trade [Helpman et al., 2008], fixed effects Poisson Pseudo Maximum Likelihood (PPML) [Santos Silva and Tenreyro, 2006] seems to be the only reliable estimator. As shown, PPML is consistent against model misspecification and heteroskedasticity [Staub and Winkelmann, 2012]; recent research even shows that PPML can consistently handle excess zeros [Santos Silva and Tenreyro, 2011].

However, PPML has an additional advantage that has been so far neglected in the literature. PPML already allows for a structural fit of the gravity trade model. As Fally [2012] shows estimated fixed effects are consistent with the definitions of multilateral resistance indexes (i.e. general equilibrium effects) and the equilibrium constraints that they have to satisfy. Given the adding-up property of PPML (i.e. fitted output/expenditure equals observed output/expenditure), fixed effects can already be harnessed to directly deduce multilateral resistance indexes from reduced-form estimation. Fally's approach is insofar promising as it combines the advantages of a reduced-form estimation with that of a structural estimation, i.e. one can stay with the very handy PPML for estimation and for the construction of multilateral resistance indexes just obversed output and expenditure, and estimated fixed effects are required. Fally's approach should significantly ease comparative statics and incidence analysis; conducting trade policy analyses in a gravity trade model context should become much easier.

In the following, we are going to review the recent literature on gravity trade model estimation with a special emphasis on agriculture. However, the standard Anderson and van Wincoop Model [2003] will be introduced before the review to establish a common basis for discussion. Afterwards, different estimators are compared before we moving on to the estimation framework. Finally, we conclude.

## 2 A *Structural* Gravity Trade Model

The Anderson and van Wincoop Model is the first *structural* gravity trade model that explicitly accounts for general equilibrium effects, i.e. not only absolute changes in bilat-

[1] Here and in the following, the notation gravity trade model always refers to the standard Anderson and van Wincoop Model [2003].

[2] See e.g. Prehn and Brümmer [2012], Kotchoni and Larue [2012], Haq et al. [2012], Xiong and Sixia [2012] and Philippidis et al. [2011].

eral trade costs are considered but also relative changes in relation to changes in average bilateral trade costs. Bilateral trade costs are compared to both average bilateral trade costs of the respective importer and those of the respective exporter. Following Anderson and van Wincoop, these average bilateral trade costs are also referred to as inward and outward multilateral resistance index, respectively.

The *structural* model is given in equation [1] – [3].

[1] $$X_{ijk} = \frac{Y_{ik}}{\Pi_{ik}^{-\theta_k}} \times D_{ijk}^{-\theta_k} \times \frac{E_{jk}}{P_{jk}^{-\theta_k}}$$

[2] $$P_{jk}^{-\theta_k} = \sum_i \frac{Y_{ik} D_{ijk}^{-\theta_k}}{\Pi_{ik}^{-\theta_k}}$$

[3] $$\Pi_{ik}^{-\theta_k} = \sum_j \frac{E_{jk} D_{ijk}^{-\theta_k}}{P_{jk}^{-\theta_k}}$$

where, $X_{ijk}$ denotes the export value of country i to country j in sector k, $Y_{ik}$ i's total sectoral output, and $E_{jk}$ j's total sectoral expenditure. In addition, $D_{ijk}$ captures sector-specific bilateral trade costs from i to j, and $\theta_k$ is the corresponding sectoral trade flow elasticity. $\Pi_{ik}$ is a sectoral measure for i's outward multilateral resistance and $P_{jk}$ for j's inward multilateral resistance.

It is common practice first to estimate the reduced-form model [1] by means of a fixed effects approach [Feenstra, 2004],[3] where the corresponding econometric model is given as

[4] $$X_{ijk} = \exp\left[\alpha_0 + e_{ik} - \theta_k D_{ijk} + m_{jk}\right] + \varepsilon_{ijk}$$

where $\varepsilon_{ijk}$ denotes an error term, and $e_{ik}$ and $m_{jk}$ are exporter and importer fixed effects, respectively. $\alpha_0$ is a constant.

The estimates $\widehat{D_{ijk}^{-\theta}}$ then can be used to simultaneously solve for the equilibrium conditions [2] – [3] [Anderson and Yotov, 2012]. The corresponding estimates $\widehat{P_{jk}^{-\theta_k}}$ and $\widehat{\Pi_{ik}^{-\theta_k}}$, in turn, can be used for comparative statics and incidence analysis.

Obviously, the validity of the whole approach crucially depends on the consistency of the reduced-form estimation. Therefore, we first focus on this.

[3]The nonlinear programming approach of Anderson and van Wincoop should not anymore be applied, as it requires strong assumptions which are usually not fulfilled in practice [Egger and Larch, 2012].

## 3 Gravity Estimation, Poisson Pseudo Maximum Likelihood, and Adding-up

With the seminal paper of Santos Silva and Tenreyro [2006] a discussion started on the appropriate estimation of gravity trade models. Where the discussion on *aggregate* gravity trade models now seems to be settled, the discussion on *disaggregate* gravity trade models still goes on. The main problems are excess zeros and overdispersion[4], which is why some researchers [Burger et al., 2009] propose zero-inflated count data models instead. However, both alternatives (i.e. zero-inflated Poisson/Negative Binomial Pseudo Maximum Likelihood (ZIPPML/ZINBPML)) suffer under model misspecification, i.e. if the data generating process does not follow a zero-inflated Poisson/Negative Binomial Distribution, estimates are biased [Staub and Winkelmann, 2012]; Negative Binomial Pseudo Maximum Likelihood even suffers under scale dependence, i.e. depending on the chosen scale of the endogenous estimates either converge against PPML or against Gamma Pseudo Maximum Likelihood [Bosquet and Boulhol, 2010].

Also the critic brought to PPML that it could not appropriately deal with excess zeros and overdispersion is not justified. Neither, PPML is biased by excess zeros [Santos Silva and Tenreyro, 2011], solely the constant cannot anymore be interpreted as before, enclosing now an additional zero-inflation parameter [Staub and Winkelmann, 2012], nor, is overdispersion really of a problem; it is standard to estimate the variance by means of a non-parametric sandwich estimator[5], which converges asymptotically against the true variance.

All in all, from the estimation perspective, there is no reason why PPML should not be applied to *disaggregate* gravity trade models. Rather, PPML has an additional property which makes it even more preferable. PPML is the only estimator which fulfills the adding-up property, i.e. the sum of fitted trade flows (i.e. fitted output/expenditure) equals the sum of observed trade flows (i.e. observed output/expenditure) [Fally, 2012]. The usefulness of this property will become obvious in the next section.

## 4 Reduced-form Estimation and Structural Fit

Former remarks are just concerned with reduced-form estimation, however, as we said above, PPML has an additional advantage when it comes to a structural approach.

As Fally [2012] shows any fixed effects approach can already be used to derive multilateral resistance indexes from reduced-form estimation. However, for the construction of multilateral resistance indexes still fitted output and expenditure, and estimated fixed effects are required. If estimation would be consistent, there would be no problem. However, as we discussed above, only PPML is consistent.

[4]Overdispersion is given if the conditional variance is larger than the conditional expectation.
[5]Following Santos Silva and Tenreyro [2006], cluster-robust standard errors are now standard.

For fixed effects PPML, the construction of multilateral resistance indexes can even be simplified. Given the adding-up property of PPML, that fitted values always equal observed values, observed values can already be used to construct multilateral resistance indexes. Considering this, the unique solutions to the equilibrium conditions [2] and [3] are $\widehat{P_{jk}^{-\theta}} \equiv \frac{E_{jk}}{E_{0k}} exp(-\hat{m}_{jk})$ and $\widehat{\Pi_{ik}^{-\theta}} \equiv E_{0k} Y_{ik} \, exp(-\hat{e}_{ik})$, where $E_{0k}$ denotes the sectoral expenditure of a reference country 0.

Compared to standard numerical methods [Anderson and Yotov, 2010], Fally's approach is by far easier to implement, just reduced-form fixed effects estimates are required, and comparative statics and incidence analyses are still consistent.

Standard comparative statics can directly be calculated, e.g. country-specific bilateral trade cost effects

[5]
$$\Delta \frac{X_{ijk}}{Y_{ik}E_{jk}} = 100 \times \left[ \frac{\left(\widehat{D_{ijk}^{-\theta_k}}\right)^c \left(\widehat{\Pi_{ijk}^{-\theta_k}}\right)^c \left(\widehat{P_{jk}^{-\theta_k}}\right)^c}{\left(\widehat{D_{ijk}^{-\theta_k}}\right)\left(\widehat{\Pi_{ik}^{-\theta_k}}\right)\left(\widehat{P_{jk}^{-\theta_k}}\right)} - 1 \right]$$

where superscript $c$ indicates the counter-factual policy scenario.[6]

## 5 Conclusions

In this paper, we take up again the discussion of gravity trade model estimation in agriculture. We review recent literature to show that Poisson Pseudo Maximum Likelihood (PPML) is the only reliable estimator currently available. All other estimators are biased, as they suffer in particular from model misspecification and scale dependence [Prehn and Brümmer, 2011].

PPML has an additional advantage that has been so far neglected in the literature. It already allows for a structural fit of the gravity trade model. Given the adding-up property of PPML, fixed effects can be harnessed to directly deduce multilateral resistance indexes (i.e. general equilibrium effects) from a reduced-form estimation; hence, the advantages of a reduced-form estimation can be combined with that of a structural estimation. The approach developed by Fally [2012] is so promising as it should significantly ease comparative statics and incidence analysis; it should make gravity trade model estimation more tractable for trade policy analysis.

[6]For incidence analysis and derived measures as constructed home bias, domestic bias, and foreign bias see Anderson and Yotov [2010] and Anderson et al. [2012], respectively.

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