CeGE-Discussion Paper

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Center for Globalization and Europeanization of the Economy

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

June 2007

ISSN 1439-2305

This paper is based on a presentation at the “9th Göttingen Workshop on International Economic Relations” at the Georg-August-University of Göttingen in collaboration with the Center of Globalization and Europeanization of the Economy (CeGE), March 22-24, 2007.

The aim of this annual workshop is to offer a forum for young researchers from the field of International Economics to present and to discuss their current topics of research with other experts. The workshop also provides the opportunity to gain an overview of recent developments, problems and methodological approaches in this field.

Detailed information on past workshops and the planning for the 2008 workshop are available at http://www.vwl.wiso.uni-goettingen.de/workshop. Do not hesitate to contact Prof. Dr. Gerhard Rübel, CeGE (gruebel@uni-goettingen.de) for further questions.

The Log of Gravity Revisited

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Acknowledgements
We would like to thank Stephan Klasen, João Santos Silva, Stefan Sperlich, Walter Zucchini and the participants in the Goettinger Workshop "Internationale Wirtschaftsbeziehungen" for their helpful comments and suggestions.

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The Log of Gravity Revisited

Abstract

This paper evaluates the performance of alternative estimation methods for multiplicative and log models with heteroskedasticity. Contrary to Santos Silva and Tenreyro (2006), the results of a simulation study indicate that the Pseudo Poisson Maximum Likelihood estimator (PPML) is not always the best estimator. New estimates of the gravity equation are obtained for three different datasets with traditional methods (OLS and FGLS) and with the PPML. We find that the PPML assumption concerning the pattern of heteroskedasticity is, in most cases, rejected by the data and PPML estimates are outperformed by OLS and FGLS estimates in out-of-sample forecast.

JEL classification: C33, Q25

Keywords: Simulations; Poisson regression; constant-elasticity models; heteroskedasticity; Feasible Generalized Least Squares (FGLS); Maximum Likelihood

1. Introduction

Santos Silva and Tenreyro (2006) claim that constant-elasticity models should be estimated in their multiplicative form, instead of applying traditional OLS estimation techniques to the log-linearized models. The authors propose a Poisson Pseudo-Maximum Likelihood (PPML) estimation technique that is claimed to be consistent in the presence of heteroskedasticity and to provide a natural way of dealing with zero values of the dependent variable.

In their paper, the gravity equation for international trade, a widely used model to predict bilateral trade flows, is taken as an example of constant-elasticity models. The general practice has been to estimate the log-linearized version of the gravity model using OLS (ordinary least squares)[1]. However, in the related empirical literature we can also find several attempts to deal separately with heteroskedasticity (Porojan, 2001) and zero values (Helpman

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[1] Feenstra (2004) presents in Chapter 5 a revision of articles applying the gravity model for international trade.

et al., 2006). Other typical applications of multiplicative models are the estimation of Cobb-Douglas-type production functions and the estimation of the STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) model in environmental economics.

In this paper, we reconsider the evidence presented by Santos Silva and Tenreyro. The novelties of the research are threefold. First, we argue that the performance of the PPML estimator should be also compared to Feasible Generalized Least squares (FGLS) techniques applied to the linearized model and not only to OLS techniques. Second, we consider a different way of dealing with zero values of the dependent variable. We generate a dependent variable that becomes zero with a certain probability (p) and that remains continuous with probability (1-p). In a further step, zeros are randomly created depending on a threshold value of one of the regressors to imitate some minimum conditions that are necessary for a positive dependent variable. Finally, new estimates of the gravity equation are obtained for three different datasets with traditional methods (OLS and FGLS) and with the PPML.

In line with Santos Silva and Tenreyro, we run a simple simulation to evaluate the performance of alternative estimation methods (OLS, NLS, Gamma Pseudo Maximum Likelihood (GPML), PPML and FGLS) for multiplicative and log models with heteroskedasticity. Contrary to Santos Silva and Tenreyro (2006), the results of the simulation study indicate that the Pseudo Poisson Maximum Likelihood estimator (PPML) is not always the best estimator.

In addition, new estimates of the gravity equation are obtained for three different datasets with traditional methods (OLS and FGLS) and with the PPML. We find that the PPML assumption concerning the pattern of heteroskedasticity is, in most cases, rejected by the data and PPML estimates are outperformed by OLS and FGLS estimates in out-of-sample forecast.

The next section focuses on a discussion of the PPML and the FGLS estimation techniques and their consistency in the presence of heteroskedasticity. Section 3 presents the simulation results in the presence of homoskedasticity, heteroskedasticity, and with a dependent variable that can take on zero values. Section 4 applies the PPML and other alternative estimation techniques to real data and discusses the estimation results. In Section 5, some conclusions are drawn.

2. Alternative Estimators

As mentioned above, the traditional way to estimate constant-elasticity models is to linearize the original multiplicative model using a log-log transformation. Let us assume that the original stochastic model is given by,

$$y_i = \exp(x_i \beta_i) \varepsilon_i \qquad (1)$$

where $E(\varepsilon_i \mid x) = 1$

Assuming that y_i is positive, the model can be linearized by taking logs,

$$\ln y_i = x_i \beta_i + \ln \varepsilon_i \qquad (2)$$

where $\ln E(\varepsilon_i \mid x) = 0$; $E(\ln \varepsilon_i \mid x) \neq 0$

The original multiplicative model given by Equation (1) can be directly estimated using NLS or maximum likelihood techniques, whereas Model (2) can be estimated simply by OLS. $E(\ln \varepsilon_i \mid x) \neq 0$ (Known as Jensen's inequality) only affects the intercept of Equation (2)[2], but leaves the coefficients of the other regressors unaffected. However, in the presence of heteroskedasticity, Least Squares estimation is no longer efficient. This problem can be tackled by controlling for heteroskedasticity.

The estimation technique proposed by Santos Silva and Tenreyro (2006) is a pseudo-maximum likelihood estimator based on some assumptions about the functional form of the conditional variance. Under the assumption that the conditional variance is proportional to the conditional mean, β can be estimated by solving a set of first-order conditions,

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[2] The estimation of the intercept β_0 will be biased, but not the estimation of the slope coefficients ($\beta_1,..,\beta_k$).

$$\sum_{i=1}^{n}\left[y_i - \exp\left(x_i\tilde{\beta}\right)\right]x_i = 0 \tag{3}$$

where y_i is the dependent variable, x_i are the explanatory variables, and β are the parameters to be estimated. The estimator based on (3) gives the same weight to all observations, the LS and NLS estimators give more weight to observations with large exp(x_iß).

The data do not have to follow the Poisson distribution and the dependent variable does not have to be an integer. Since the assumption of proportionality between the conditional variance and the conditional mean does not always hold, inference should instead be based on a robust covariance matrix estimator that specifically corrects for heteroskedasticity in the model.

An alternative estimation technique that is also efficient in the presence of heteroskedasticity is the Feasible Generalised Least Squares (FGLS) estimator, which can be applied to the linearized model. The FGLS weighs the observations according to the square root of their variances, and is given by,

$$\beta_{FGLS} = \left(x'\hat{\Omega}^{-1}x\right)^{-1}x'\hat{\Omega}^{-1}y \tag{4}$$

where $\hat{\Omega}$ is the weighting matrix.

It can be shown that even if the weights used in FGLS estimation are biased due to a biased intercept (resulting in a biased estimation of the residuals variance)[3], FGLS would still provide consistent estimates. In case of an unknown form of heteroskedasticity, Feasible Generalized Least Squares (FGLS) can be applied and the variance of the disturbances must be estimated. This method should be well suited to estimating regression coefficients in the presence of heteroskedasticity. Henceforth, the comparison should be made between FGLS and gamma Pseudo ML (GPML) or Poisson Pseudo Maximum Likelihood (PPML)) estimation.

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[3] One could discuss whether the estimation of the residuals' variance -needed for FGLS- will be biased under those circumstances. However, even if we admit that the variance would be biased, it can be shown that FGLS would still be asymptotically consistent (Greene, 2000, p. 618).

3. Simulation Study

A dataset with the same properties as described by Santos Silva and Tenreyro (2006) is generated to compare different estimation techniques in the presence of heteroskedasticity. The multiplicative constant elasticity model considered is,

$$y_i = \tilde{\beta}_0 \, x_{1i}^{\beta_1} x_{2i}^{\beta_2} \eta_i \tag{5}$$

η_i is a log-normal random variable with mean 1 and variance σ_i^2 in the absence of heteroskedasticity. x_{1i} is log-normal and x_{2i} is dichotomous with values of e^0 and e^1 with a probability of 0.6 for the first value and a probability of 0.4 for the second value.

Equation 5 can also be expressed as,

$$\mu(x_i \beta) := E[y_i \mid x] = \exp(\ln \tilde{\beta}_0 + \beta_1 \ln x_{1i} + \beta_2 \ln x_{2i}) \tag{6}$$

where $X_{1i} := \ln x_{1i}$; $X_{2i} := \ln x_{2i}$ and $\ln \tilde{\beta}_0 := \beta_0$

From distributional theory, it follows that X_{1i} is drawn from a standard normal distribution and X_{2i} is a binary variable that takes the value 1 with a probability of 0.4. The two covariates are independent and the true values for the coefficients are: $ß_0 = 0$, $ß_1 = 1$ and $ß_2 = 1$.

In line with Santos Silva and Tenreyro (2006), we assess the performance of different estimators (NLS, GPML, PPML, OLS, FGLS)[4] under homoskedasticity and heteroskedasticity. We can distinguish four cases:

Case 1: $V(\eta_i) = \mu(x_i,\beta)^{-2}; V[y_i \mid x] = 1$

Case 2: $V(\eta_i) = \mu(x_i,\beta)^{-1}; V[y_i \mid x] = \mu(x_i,\beta)$

Case 3: $V(\eta_i) = 1; V[y_i \mid x] = \mu(x_i,\beta)^2$

Case 4: $V(\eta_i) = \exp(x_{2i}) + \mu(x_i,\beta)^{-1}; V[y_i \mid x] = \mu(x_i,\beta) + \exp(x_{2i})\mu(x_i,\beta)^2$

In Case 1, the NLS assumptions hold. In Case 2, the conditional variance equals its conditional mean as in the PPML assumptions. OLS, FGLS and GPML conditions are

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[4] Tobit and truncated-OLS simulation results are not presented since these methods show a very poor performance.

fulfilled in Case 3 (homoskedasticity), and finally in Case 4, the conditional variance does not only depend on the mean but it is also a function of one of the explanatory variables (heteroskedasticity). We argue that in Case 4 of heteroskedasticity, which was identified as a severe problem in many applications (e.g. when analyzing trade flows in the framework of the gravity model), FGLS instead of OLS should be used for comparison purposes.

In a first set of simulations, we study the performance of the estimators for the different models considered and for the four specifications of the disturbances outlined above. We focus on the estimators with a good performance in the experiments of Santos Silva and Tenreyro (2006), disregarding those with a poor performance (Tobit, OLS (y+1), truncated-OLS) and adding the FGLS estimator.

Deviating from Santos Silva and Tenreyro (2006), we will evaluate the performance of the estimators not only by looking at the bias of the estimates but also by computing their expected loss. Most economic simulation studies consider unbiasedness or a small bias to be the most desirable property of an estimator. Therefore the bias is used as the main criterion to compare the quality of different estimators. But this approach is in many cases misleading since – due to the fact that over- and underestimations cancel each other out – unbiased estimators are not necessarily also good estimators.[5]

In statistical decision theory, one therefore looks at the risk of an estimator, defined as its expected loss,

$$R(\beta,\hat{\beta}) = E_{\beta}L(\beta,\hat{\beta}) \tag{7}$$

The way the loss function $L(\beta,\hat{\beta})$ is defined depends on the individual needs in each statistical analysis. As argued above, we only consider the class of loss functions where over-

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[5] We give a simple example to illustrate this: let the true parameter be $\beta = 1$. We define an estimator $\hat{\beta} = 0$ half of the time and $\hat{\beta} = 2$ the other half of the time. Clearly, this is a very bad estimator, but it is unbiased. The constant estimator $\hat{\beta} = 1.1$, in contrast, is biased but obviously better than the above estimator.

and underestimations cannot cancel out as in case of the bias. The simplest loss function which is adequate for our purposes is the absolute error loss,

$$L(\beta, \hat{\beta}) = \left|\beta - \hat{\beta}\right| \tag{8}$$

Nevertheless, one could use other loss functions as well, e.g. the squared error loss.

In a second set of experiments, we study how zero values in the dependent variable affect the performance of the estimators, using a data generation mechanism that produces a percentage of observations with zero values in y_i, but that differs from the one used by Santos Silva and Tenreyro (2006)[6]. In Santos Silva and Tenreyro (2006), the Poisson model does very well when the dependent variable is rounded to integers; in fact, applications like these favour the Poisson model. Santos Silva and Tenreyro argue that this indicates that PPML is adequate for modeling zero-trade and related problems. This conclusion seems questionable since the rounding alters the random data, favoring the Poisson model. Hence, we suggest a more straightforward way to see what happens in cases of zero-trade or related problems, namely setting a certain percentage of the dependent variable to zero. We do this in two different ways: first, we choose a certain percentage, say 15 percent, of all observations and set it to zero. Second, we only create zeros in a certain group assuming that there is an underlying pattern that is responsible for this, say half of the 30 percent poorest/smallest countries, according to one or more of the independent variables. This pattern is reasonable for many relevant real cases including the gravity model, since zero trade mainly occurs among poor or small countries.

Tables 1 and 2 summarizes simulation results for sample sizes of 1,000 and 10,000 replications. The expected loss, the bias, and the standard error of the two parameters of interest (β_1 and β_2) are presented. Table 1 shows the results for the first set of simulations. The NLS shows a good performance in Case 1 and the PPML is the best in Case 2, in which

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[6] In Santos Silva and Teneyro (2006) the dependent variable was generated rounding to the nearest integer the values of y_i.

the PPML assumptions are fulfilled. PPML and FGLS display a very good performance (lower expected loss) in Cases 3 and 4, and both are superior to PPML.

Table 1. Simulation results, regular case

Table 2 shows the results for the second set of simulations, in which the dependent variable is generated with a percentage of zero values. When the zero values are generated randomly, the Gamma and the FGLS still perform quite well in Cases 3 and 4, and both present lower expected losses than the PPML. However, when the zero values are generated with a given pattern, FGLS is superior to Gamma and PPML in these cases.

Table 2. Simulation results with zeros

4. The gravity model: Estimation results

4.1 Original versus log-log version of the gravity model

According to the generalised gravity model of trade, the volume of exports between pairs of countries in year t, X_{ijt}, is a function of their incomes (Y_{it}, Y_{jt}), their incomes per capita (YH_{it}, YH_{jt}), their geographical distance ($DIST_{ij}$) and a set of dummies that represents any other factors aiding or preventing trade between pairs of countries (F_{ij}),

$$X_{ijt} = \beta_0 \; Y_{it}^{\beta_1} Y_{jt}^{\beta_2} YH_{it}^{\beta_3} YH_{jt}^{\beta_4} DIST_{ij}^{\beta_5} F_{ij}^{\beta_6} \; u_{ijt} \tag{9}$$

where u_{ijt} is the error term.

Taking natural logarithms from equation (9) and replacing F_{ij} for a number of specific variables, the log-log model is given by,

$$\begin{aligned} \ln X_{ijt} &= \alpha_{ij} + \beta_1 \ln Y_{it} + \beta_2 \ln Y_{jt} + \beta_3 \ln YH_{it} + \beta_4 \ln YH_{jt} + \\ &+ \beta_5 \ln DIST_{ij} + \beta_6 ADJ_{ij} + \beta_7 LANG_{ij} + \beta_8 REM_{it} + \sum_k \lambda_k PTA_{ij} + \mu_{ijt} \end{aligned} \tag{10}$$

where:

ln denotes variables in natural logs.

X_{ijt} are the exports from country i to country j in period t at current US$.

Y_{it}, Y_{jt} indicate the GDP of countries i and j respectively, in period t at current PPP US$.

YH_{it}, YH_{jt} denote incomes per capita of countries i and j respectively, at current PPP US$ per thousand inhabitants in period t.

$DIST_{ij}$ is the great circle distance between countries i and j.

ADJ is a dummy that take the value of one when countries i and j share a border.

LANG is a dummy for common language.

REM_{it} is the average distance of country *i* to exporter partners, weighted by exporters' GDP share in world GDP.

The model includes trading blocs' dummy variables, defined as PTA_{ij} which evaluate the effects of preferential trading agreements (PTAs). Integration dummies are described in more detail below. α_{ij} are the specific effects associated to each bilateral trade flow. They are a control for all the omitted variables that are specific for each trade flow and that are time invariant.

A high level of income in the exporting country indicates a high level of production, which increases the availability of goods for export. Therefore we expect β_1 to be positive. The coefficient of Y_j, β_2, is also expected to be positive since a high level of income in the importing country attracts higher imports. The coefficient estimate for income per capita of the exporters, β_3, may be negatively or positively signed depending on the type of goods exported. The coefficient of the importer income per capita, β_4, also has an ambiguous sign, for similar reasons. Another factor that may influence these coefficient estimates is the composition effect that influences supply and demand. Each country produces and exports a different mix of commodities (supply) and the mix of goods demanded is also different for each country. The distance coefficient is expected to be negative since it is a proxy of all possible trade costs. The coefficient for remoteness is expected to be positive, given that pair of countries that are relatively far away from most of their trading partners are expected to trade more to each other.

In some of the results presented below, specific trading bloc dummies are included to model trade creation and trade diversion effects of trade (see Soloaga and Winters (2001); Chen and Tsai (2005) and Carrère (2005)).

The specification of the Viner's trade creation and trade diversion for a single period is given by,

$$\ln X_{ij} = EV_{ij} + \sum_k \gamma_k D_k + \sum_k \delta_k D_{ki} + \sum_k \rho_k D_{kj} \qquad (11)$$

where X_{ij} are exports from country i to country j, EV_{ij} is defined as the rest of explanatory variables of the gravity equation above. $\mathrm{D_k}$ is a dummy that takes the value 1 if both countries, i and j, belong to the same economic bloc, 0 otherwise. D_{ki} is a dummy that takes the value 1 if i is a member of bloc k and j belongs to the rest of the world, 0 otherwise. D_{kj} is a dummy that takes the value 1 if j is a member of bloc k and i belongs to the rest of the world, 0 otherwise. γ_k measures the extent to which trade is higher than normal levels if both countries, i and j are members of the bloc, δ_k measures the extent to which members' exports are higher than normal levels to non-member countries and ρ_k measures the extent to which members' imports are higher than normal levels from non-member countries. δ_k and ρ_k could be interpreted as a measure for trade diversion effects; but they might also combine trade diversion and openness effects.

4.2 Main Results

Different versions of models (9) and (10) are estimated using alternative techniques (OLS, FGLS, Harvey model[7], PPML and Heckman selection model) for three different datasets. The first one is a sample of 180 countries over the period 1980-2000 from Rose (2005). The

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[7] Harvey's model of multiplicative heteroskedasticity has also been estimated since it is a very flexible and model that includes most of the useful formulations as special cases. The general formulation is $\sigma_i^2 = \sigma^2 \exp\left(z_i^{'}\alpha\right)$.

second dataset consists on a sample of 47 countries from Martínez-Zarzoso (2003) covering the period 1980-1999. Finally, a third sample of 65 countries from Márquez, Martínez and Suárez (2007) is used, with data for every five years over the period 1980-1999. The traditional gravity model as well as the theoretically justified gravity model (Anderson and van Wincoop, 2003) with multilateral resistance terms specified as exporter and importer dummy variables are considered.

Table 3 shows the results for the *traditional gravity model*, as specified in equations (9) and (10) for the first dataset[8]. With comparative purposes, we show the results for the year 1990 as in SST. However, the estimated parameters are not directly comparable since the number of countries is different and also the definition of the dependent and some of the independent variables. Our purpose is only to present estimation results for different datasets in order to evaluate/put into perspective the use of the PPML as the new "workhorse" for the estimation of gravity models[9].

Table 3. Estimation results: Traditional gravity model

The estimated coefficients for the income variables are closer to the theoretical value of one when the equation is estimated using OLS and FGLS. The fact that the income elasticities for the exporter and for the importer countries are equal in magnitude according to the PPML estimation is not indicative of a correct specification. Asymmetries have been found before in the literature and can also be theoretically justified.

In contrast to SST (2006), the variables colony and common border are also statistically significant, although the first one is lower in magnitude when PPLM is used, compared to OLS. The OLS and FGLS estimates for *regional,* indicates that the integration dummy is statistically significant, whereas using PPML it is significant but much lower in magnitude

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[8] The theoretically modified gravity model was also estimated for this sample using OLS and FGLS techniques, but the PPML estimation presented some problems since the maximization algorism could not find a solution.

[9] SST page 649.

than using OLS. Instead, the Harvey model produces a non significant coefficient for the regional dummy.

Concerning geographical distance, in line with SST the estimated elasticity is significantly lower in magnitude in the PPLM estimation, whereas in the FGLS and Harvey model it is lower than in OLS but higher than in PPML.

Table 4 shows the results for the *theoretically justified gravity model* for the second and third data sets. The first three columns show the estimated coefficients for the OLS, FGLS and Harvey model. The last two columns present the results obtained using Poisson and the Heckman Selection model that controls for zero values in the dependent variable. In the context of the gravity model of trade, the presence of zeros in the dependent variable is mostly due to absence of trade rather than to missing values. This raises a problem of selection bias. Heckman-type models are able to tackle the problem of sample selection bias (there are different motives for participating or not participating in a certain economic activity that have to be identified before running the regression for the agents participating).

Comparing the results of the five specifications, for both samples we observe that the role of distance is significantly reduced under Poisson. Speaking the same language has always a positive effect on trade, but the effect is also substantially reduced (halved) when using Poisson in comparison to OLS, FGLS, Harvey or Heckman. A common border has always a positive effect on exports of the first sample (65 countries) under all estimation techniques. However, for the second sample (47 countries) OLS and FGLS and Harvey predict no significant effects and Poisson produce a positive and significant effect. The coefficient is not shown in the last column because the variable common border was used only in the selection equation.

With respect to the free-trade-agreement variables, for the first sample only Poisson predicts a significant and positive effect. For the second sample, Poisson predicts always positive and significant effects whereas the additional techniques produce negative effects for the EU agreement (but non-significant when correcting for heteroskedasticity using FGLS and Harvey) and positive and significant effects for the NAFTA, CACM and CARICOM agreements.

Table 4. Estimation results: Theoretically justified gravity model

A panel data version of the gravity model is also estimated, adding to the traditional specification dyadic random effects and time effects. The results are shown in Table 5. The FGLS model shows more reasonable coefficients than the PPML in terms of theoretical justification. For example, Poisson estimates reveal puzzling asymmetries in the coefficients on exporter's and importer's GDPs. The estimated GDP elasticities are 3.81 and -0.10 respectively, both statistically significant. Finally, the root mean squared error (RMSE) indicates that the FGLS model corrected for autocorrelation and heteroskedasticity has a better forecast performance than the alternative methods.

4.3 Robustness Check

In this section we first present the results obtained when testing for the pattern of heteroskedasticity. In addition, we also investigated the out-of-sample forecast performance of the alternative estimates.

To determine if the pattern of heteroskedasticity assumed by the different models is acceptable, a Park-type test is used to check for the adequacy of the log-linear model. The Park-type test consist on estimating the equation specified as,

$$\ln\left(y_i - \hat{y}_i\right)^2 = \ln(\lambda_0) + \lambda_1 \ln \hat{y}_i + \varepsilon_i \tag{12}$$

Acceptation of the null hypothesis: H_0: $\lambda_1=2$ based on a robust/non robust covariance estimator would be in support of the log-linear model.

The results from a Gauss-Newton regression are used to test for the proportionality assumption (the conditional variance is proportional to the conditional mean). The Gauss-Newton regression given by,

$$\left(y_i - \hat{y}_i\right)^2 / \sqrt{\hat{y}_i} = \lambda_0 \sqrt{\hat{y}_i} + \lambda_0 (\lambda_1 - 1) \ln(\hat{y}_i) \sqrt{\hat{y}_i} + \mu_i \qquad (13)$$

The proportionality hypothesis can be checked by testing for the significance of $\lambda_0(\lambda_1-1)$ in Equation (13). The hypothesis will be accepted if the parameter is statistically insignificant.

Table (6) shows the results. Both tests indicate that the underlying hypotheses are rejected by the data. As pointed out by SST, the proportionality assumption is unlikely to hold, therefore the PPLM does not fully account for the heteroskedasticity in the model. The authors mentioned that the inference should then be based on a robust covariance matrix estimator. In this context FGLS could be a very useful method. The only shortcoming of standard FGLS techniques is that the relation between the residuals and the independent variables is restricted to a linear model. In presence of Jensen´s inequality, as well as for other functional forms different from the linear model, this simplifying assumption lowers estimation quality. Nevertheless, for most practical purposes this problem could be solved by using more sophisticated methods based on the results obtained in Carroll (1982), Robinson (1987) and Delgado (1992 and 1993). These authors propose a semi-parametric version of FGLS that consists on estimating the relation between the residuals and the independent variables allowing for an unknown functional form and using non-parametric techniques.

Concerning the goodness of fit of the PPLM results, the last two rows of tables 3 and 4 (in the first and second half of the table) show the results of the “poisgof” test. The large value for the chi-square is another indicator that the poisson distribution is not a good choice. Since the distribution of exports present signs of over dispersion (the variance is larger than the mean), we scaled the standard errors using the square root of the Pearson-chi-square dispersion. The coefficients where identical to the previous analysis but the standard errors where significantly lower in magnitude. We also computed the Akaike information criteria (AIC) but the results obtained for log-linear and Poisson/gamma models are not directly comparable. The Harvey and GLS present the lowest AIC among the log-linear models.

SST show the results obtained from a Ramsey-reset test of specification error of functional form that supported the PPML estimator. However, this test is only valid for log-linear models since the alternative is the presence of non-linearities in the model. It is a linearity test, not a general specification test. Therefore, it does not test whether other relevant linear or non-linear variables have been omitted. We show in Table 4 that only for the FLGS estimator for the 65 country sample the null hypothesis of an adequately specified model has accepted.

Finally we did some cross-validation. We re-estimated the gravity model for the sample of 65 countries excluding one of them and compared the fitted values with the real values for the excluding country. We repeat the same experiment for several countries and use the PPML and the OLS and FGLS techniques. Our findings indicate that OLS and FGLS results outperformed PPML in the out-of-sample forecast[10]. The graphs shown in the Appendix indicate that OLS predictions are much closer to actual values than poisson predictions.

Another way of evaluating the forecasting performance of the different estimators is to use Stavins and Jaffe (1990) goodness of fit statistic that equals one minus Theil's U-statistic and is based on comparing predicted and actual values for the dependent variable (S&J goodness of fit). The Theil inequality coefficient lies between 0 and 1 and a value of zero indicates a perfect fit. We can compare models with this measure since it is scale invariant. The S&J (1990) goodness of fit values are shown at the bottom of Tables 3, 4 and 5. The values obtained are always higher in log-linear models, indicating that these models give a better forecast accuracy than PPML models.

5. Conclusions

The extended use of gravity models to predict international trade flows has generated an ongoing discussion concerning the estimation techniques applied. Contrary to Santos Silva and Teneyro (2006) the results of the simulations indicate that in this setting PPML is not

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[10] Results for six selected countries are shown in the Appendix.

superior to FGLS and Gamma estimates when the expected loss is used as the criterion to evaluate the performance of different estimators.

Nevertheless, we would like to point out that conclusions drawn from this type of simulation study should not be too strong, and that the winning estimation method should not be labeled “the new workhorse for the estimation of constant-elasticity models”. We have seen that small changes of the simulation setting can lead to different outcomes. Hence one should be cautious and inspect each applied situation carefully in order to find the appropriate estimation method.

The results obtained when estimated the gravity model of trade using three different samples indicate that in terms of out-of-sample forecasting FGLS, Harvey model, OLS and sample selection techniques are always preferred to PPML. Nevertheless, PPML offers some merits for applied economists. It is a very practical estimation method to deal simultaneously with heteroskedasticity and zeros in the dependent variable, since more specific methods require usually more complicated estimation techniques.[11] Hence, PPML could be a good general procedure to estimate gravity models but, empirical researchers should use this method with caution. Appropriate tests should be provided to identify the applicability and good performance of PPML. Further research should be directed to validate these results with different data sets.

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[11] As explained in previous sections, a more specific method to deal with heteroskedasticity is weighing the variables by the standard deviation of the estimated variance and a more specific way to deal with zeros in the dependent variable is a Heckman sample selection model.

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Table 1. Simulation results, regular case

	absolute error loss		**bias**		**standard deviation**	
	β1	β2	β1	β2	β1	β2
Case 1						
OLS	0.3894	0.3560	0.3894	0.3560	0.0390	0.0529
NLS	**0.0059**	**0.0137**	0.0000	0.0002	0.0075	0.0173
Gamma	0.0535	0.0652	0.0139	0.0084	0.0672	0.0827
Poisson	0.0121	0.0215	-0.0001	0.0000	0.0161	0.0274
FGLS	0.0943	0.0879	0.0795	0.0504	0.0737	0.0956
Case 2						
OLS	0.2105	0.1992	0.2105	0.1992	0.0294	0.0497
NLS	0.0259	0.0452	0.0003	0.0012	0.0327	0.0569
Gamma	0.0336	0.0508	0.0043	0.0023	0.0431	0.0638
Poisson	**0.0156**	**0.0321**	0.0001	0.0000	0.0196	0.0401
FGLS	0.0571	0.0931	0.0164	0.0008	0.0751	0.1285
Case 3						
OLS	**0.0213**	**0.0424**	0.0001	-0.0001	0.0267	0.0532
NLS	0.2734	0.2331	0.1295	0.0255	3.4097	0.7309
Gamma	**0.0253**	**0.0522**	0.0003	-0.0006	0.0315	0.0650
Poisson	0.0551	0.0807	-0.0027	-0.0008	0.0721	0.1021
FGLS	**0.0219**	**0.0450**	-0.0003	0.0001	0.0274	0.0564
Case 4						
OLS	0.1327	0.1280	0.1326	-0.1247	0.0385	0.0754
NLS	0.9386	0.5972	0.7411	0.1663	20.5992	9.6913
Gamma	**0.0463**	**0.0855**	0.0030	-0.0022	0.0589	0.1073
Poisson	0.0777	0.1151	-0.0062	-0.0055	0.1030	0.1466
FGLS	**0.0591**	**0.1017**	0.0492	-0.0881	0.0506	0.0861

Note: The absolute error loss is defined in Equations 7 and 8 in the main text.

Table 2. Simulation results with zeros in the dependent variable

	absolute error loss		**bias**		**standard deviation**	
zeros at random	β1	β2	β1	β2	β1	β2
Case 1						
OLS	0.3900	0.3556	0.3900	0.3556	0.0429	0.0586
NLS	0.0694	0.0889	0.0043	0.0080	0.0907	0.1226
Gamma	0.0583	0.0721	0.0154	0.0072	0.0738	0.0920
Poisson	**0.0290**	**0.0422**	-0.0003	-0.0003	0.0379	0.0530
FGLS	0.0979	0.0903	0.0826	0.0539	0.0760	0.0975
Case 2						
OLS	0.2104	0.1993	0.2104	0.1993	0.0322	0.0529
NLS	0.0743	0.1038	0.0045	0.0073	0.0963	0.1371
Gamma	0.0372	0.0570	0.0045	0.0026	0.0473	0.0719
Poisson	**0.0299**	**0.0486**	-0.0011	0.0004	0.0383	0.0610
FGLS	0.0575	0.0941	0.0195	0.0033	0.0749	0.1301
Case 3						
OLS	**0.0225**	**0.0462**	-0.0003	0.0007	0.0282	0.0577
NLS	0.4154	0.3285	0.2529	0.0829	5.6568	2.4460
Gamma	**0.0292**	**0.0596**	-0.0002	0.0004	0.0366	0.0750
Poisson	0.0643	0.0937	-0.0036	-0.0028	0.0836	0.1185
FGLS	**0.0237**	**0.0483**	0.0001	0.0008	0.0299	0.0607
Case 4						
OLS	0.1322	0.1299	0.1321	-0.1254	0.0417	0.0830
NLS	0.8055	0.5406	0.5860	0.1639	7.8462	3.2434
Gamma	**0.0495**	**0.0976**	0.0046	0.0000	0.0626	0.1229
Poisson	0.0863	0.1281	-0.0084	-0.0045	0.1149	0.1649
FGLS	**0.0613**	**0.1053**	0.0500	-0.0878	0.0536	0.0941
zeros with pattern	β1	β2	β1	β2	β1	β2
Case 1						
OLS	0.3408	0.2877	0.3408	0.2877	0.0448	0.0520
NLS	**0.0116**	**0.0140**	0.0112	0.0009	0.0082	0.0176
Gamma	0.2651	0.0801	0.2620	0.0097	0.0967	0.1014
Poisson	0.0669	0.0221	0.0668	0.0008	0.0166	0.0279
FGLS	0.0760	0.0765	0.0571	0.0416	0.0714	0.0862
Case 2						
OLS	0.1938	0.1776	0.1938	0.1776	0.0336	0.0488
NLS	**0.0273**	**0.0468**	0.0118	0.0021	0.0330	0.0586
Gamma	0.2490	0.0634	0.2487	0.0027	0.0644	0.0799
Poisson	0.0664	0.0335	0.0664	0.0010	0.0205	0.0420
FGLS	0.0542	0.0889	0.0111	0.0054	0.0730	0.1227
Case 3						
OLS	**0.0248**	**0.0465**	0.0002	-0.0007	0.0311	0.0583
NLS	0.3080	0.2827	0.1818	0.0921	3.6995	2.0455
Gamma	0.2405	0.0622	0.2405	0.0011	0.0408	0.0777
Poisson	0.0736	0.0834	0.0633	-0.0027	0.0716	0.1054
FGLS	**0.0258**	**0.0491**	0.0001	0.0010	0.0325	0.0616
Case 4						
OLS	0.1200	0.1545	0.1199	-0.1529	0.0448	0.0794
NLS	0.5178	0.4039	0.3373	0.1053	4.9428	3.1924
Gamma	0.2512	0.0999	0.2508	-0.0011	0.0773	0.1261
Poisson	0.0870	0.1194	0.0601	-0.0081	0.1047	0.1521
FGLS	**0.0584**	**0.1078**	1.0465	0.9071	0.0540	0.0914

Note: The absolute error loss is defined in Equations 7 and 8 in the main text.

Table 3. Estimation results for 1990: Traditional Gravity Model

Rose (2005) Data (178 countries)	**OLS**	**FGLS**	**Harvey**	**Poisson**	**Gamma**
Lx	**Coef.**	**Coef.**	**Coef.**	**Coef.**	**Coef.**
Lyi	1.08*	1.08*	1.05*	0.80*	0.74*
Lyj	0.95*	0.96*	0.95*	0.80*	0.74*
Lyhi	0.78*	0.79*	0.82*	0.55*	0.60*
Lyhj	0.59*	0.55*	0.55*	0.61*	0.46*
Ldist	-1.33*	-1.23*	-1.13*	-0.71*	-1.06*
Border	0.71*	0.55*	0.29**	0.43*	0.45***
Comlang	0.33*	0.40*	0.45*	0.59*	0.21**
Colony	1.64*	1.38*	1.11*	0.10*	1.21*
Landl	-0.19*	-0.21*	-0.24*	-0.59*	-0.26*
Island	*0.01*	0.05*	0.12*	0.39*	0.01
Landap	-0.05*	-0.06*	-0.06*	-0.06*	-0.015
Regional	0.92*	0.44*	*0.02*	0.08*	0.45***
Custrict	1.71*	1.85*	1.71*	-0.08*	0.68***
Comcol	0.66*	0.62*	0.63*	0.81*	0.64*
Constant	-37.88*	-38.29*	-38.60*	-28.51*	-28.51*
Adj. /P-seudo R Sq	0.62	0.68	0.75	0.92	0.92
Nobs	12134	12134	12134	13974	13974
Lok-lik	-5960	-17472	-5938	-7.9e+11	-234853
AIC	11948	35955	11904	1.13e+08	469734.043
Estat gof chi2(13959)	-	-	-	1.58e+12*	-
SJ Goodness of fit	0.83898	0.8201	0.83824	0.5783	0.1851

Note: Border is a binary variable that is unity if the countries i and j share a common border, zero otherwise. Comlang is a binary variable that is unity if the countries i and j share a common language, zero otherwise. Colony is a dummy that takes the value of one if i ever colonized j or *vice versa*, zero otherwise. Landl is the number of landlocked countries in the country pair. Landap is the total area of both countries, i and j. Regional is a dummy that takes the value of one when the trading partners belong to the same trade agreement, zero otherwise. Custrict is a dummy that takes the value of one when the trading partners share a common currency, zero otherwise. Comcol is a dummy that takes the value of one if i and j were ever colonies after 1945 with the same colonizer, zero otherwise. *,**,*** denote significance at the 1%, 5% and 10% level respectively.

Table 4. Estimation results for 1990: Theoretically justified Gravity Model

65 countries	OLS	FGLS	Harvey Model	Poisson	Heckman
lx	coef.	coef.	coef.	coef.	coef.
ldist	-1.13*	-1.51*	-1.09*	-0.54*	-1.13*
lang	0.64*	1.21*	0.67*	0.27*	0.60*
adj	0.39*	0.49	0.32*	0.66*	-
fta	-0.06	0.12	-0.04	0.29*	-0.01
X,M effects	Yes	Yes	Yes	Yes	Yes
Adj. /P-seudo R Sq	0.80	0.67	-	0.96	-
Nobs	3230	3230	3230	3804	3804
Reset	6.54	1.64	5.67	6743	5.28
p-val	0.00	0.179	0.00	0.00	0.00
Log-lik	-5593.633	-998	-5560	-248300000	-6213
AIC	11389	2223	11322	496600202	12628
Estat gof chi2(3675)	-	-	-	4.97e+08*	-
SJ Goodness of fit	0.8564	0.8451	0.8576	0.4568	0.8583

47 countries	OLS	FGLS	Harvey Model	Poisson	Heckman
lx	Coef.		Coef.	Coef.	Coef.
ldist	-1.06*	-1.15*	-0.87*	-0.56*	-0.87*
isl	-0.37	-0.24	-0.25	-1.03*	-0.16
lang	1.42*	1.46*	1.36*	0.77*	1.28*
adj	-0.35	-0.60	-0.14	0.25*	-
ue	-0.37**	-0.33	-0.05	0.04*	-0.36**
nafta	1.07***	0.66	1.18***	1.32*	1.06***
cacm	1.80*	1.64*	2.29*	1.48*	1.85*
caric	1.39*	1.37*	1.79*	0.92*	1.35*
X,M effects	Yes	Yes	Yes	Yes	Yes
Adj. /P-seudo R Sq	0.82	0.86	0.92	0.97	-
Nobs	1656	1656	1656	2162	2162
Reset	-5.72	16.6	-5.29	-3914	-5.81
p-val	0.00	0.00	0.00	0.00	0.00
Log-lik	-2933.42	-2827.31	-2822.63	-8910733	-3982
AIC	6068.84	5682.62	5847.26	17821668	8166
Estat gof chi2(2061)	-	-	-	1.78e+08*	-
SJ Goodness of fit	0.8534	0.8452	0.8509	0.4942	0.8516

Note: *,**, *** denote significance at the 1%, 5% and 10% level respectively. The effects of income and income per capita variables cannot be estimated since exporter and importer effects are added as regressors.

Table 5. Estimation results for panel data 1980-1999

UE+NAFTA exports to 47 countries	**FGLS**	**FGLS**	**FGLS**	**Poisson**
Random Effects	Homosk.	Heterosk.	Heterosk.	Heterosk.
	No Autoc.	No Autoc.	Autoc.	No Autoc.
Lx	Coef.	Coef.	Coef.	Coef.
Lyi	1.09*	1.05*	0.99*	3.81*
Lyj	0.69*	0.73*	0.71*	-0.10*
Lyhi	0.77*	0.49*	0.32*	-2.98*
Lyhj	-0.09*	-0.03**	-0.54*	0.14*
Lareai	-0.10*	-0.07*	-0.05*	-0.21**
Lareaj	0.12*	0.09*	0.09*	0.57*
Lremi	-1.51*	-1.23*	-0.51*	-0.71*
Ldist	-1.26*	-1.18*	-1.19*	-1.21*
Adj	-0.21*	-0.18*	-0.16*	*-0.69*
Lang	0.86*	0.91*	0.65*	0.75*
Isl	-0.13*	-0.20*	*-0.06*	1.18*
EU	0.69*	0.55*	0.28*	0.25*
EUX	-0.19*	-0.23*	-0.25*	-0.26*
EUM	1.54*	1.18*	0.68*	-0.17*
NAFTA	0.46*	0.13	*0.09*	-3.93*
NAFTAX	-0.92*	-0.85*	-0.47*	-4.21*
NAFTAM	0.30*	0.17*	0.29*	*-0.18*
CACMM	-0.69*	-0.57*	-1.37*	-2.15*
CARICM	-0.99*	-0.98*	-1.36*	-2.33*
MAGM	-1.11*	-0.92*	-1.80*	-3.49*
MASHM	-2.17*	-2.06*	-2.96*	-4.33*
Constant	-19.12*	-19.59*	-16.79*	-43.80*
Time Effects	Yes	Yes	Yes	Yes
Nobs	12507	12507	12507	13264
SJ Goodness of fit	0.7838	0.8232	0.8267	0.5188
RMSE	2.098	2.0992	1.8276	5.274

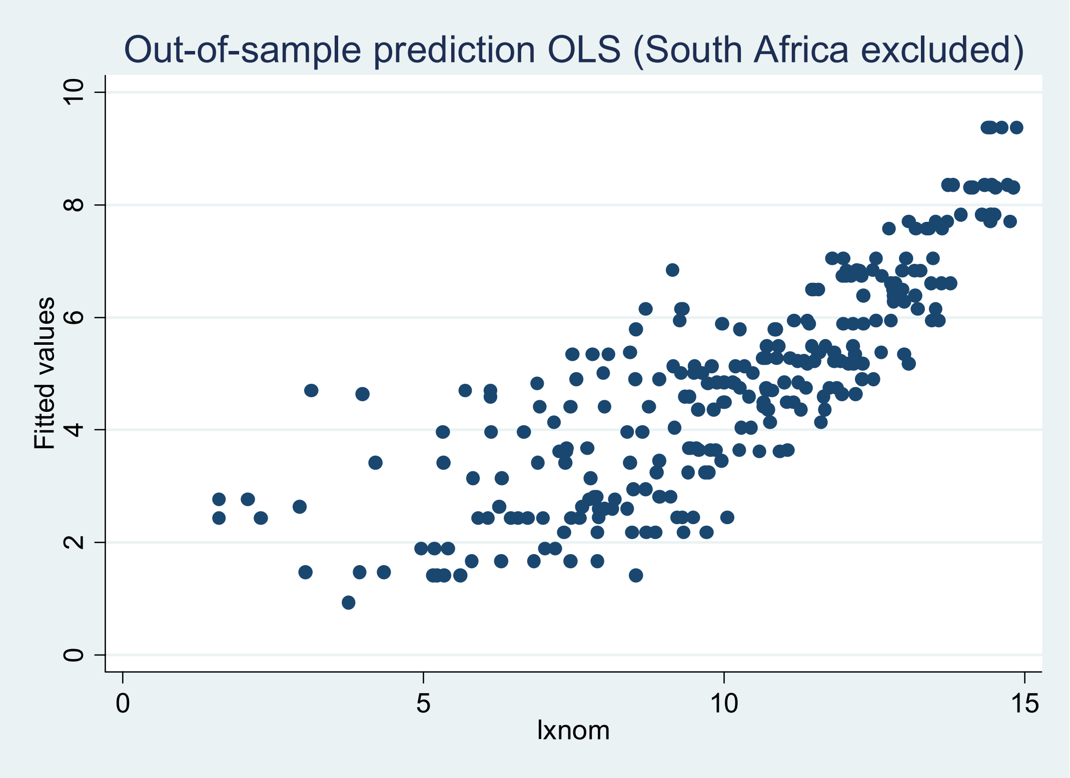
Note: EU, NAFTA, CACM, CARIC, MAGREB, MASHREK denote trade creation effects, EUM, NAFTAM, CACMM, CARICM, MAGREBM, MASHREKM denote import diversion effects and EUX, NAFTAX, CACMX, CARICX, MAGREBX, MASHREKX denote export diversion effects. *,** denote significance at the 1% and 5% level respectively.

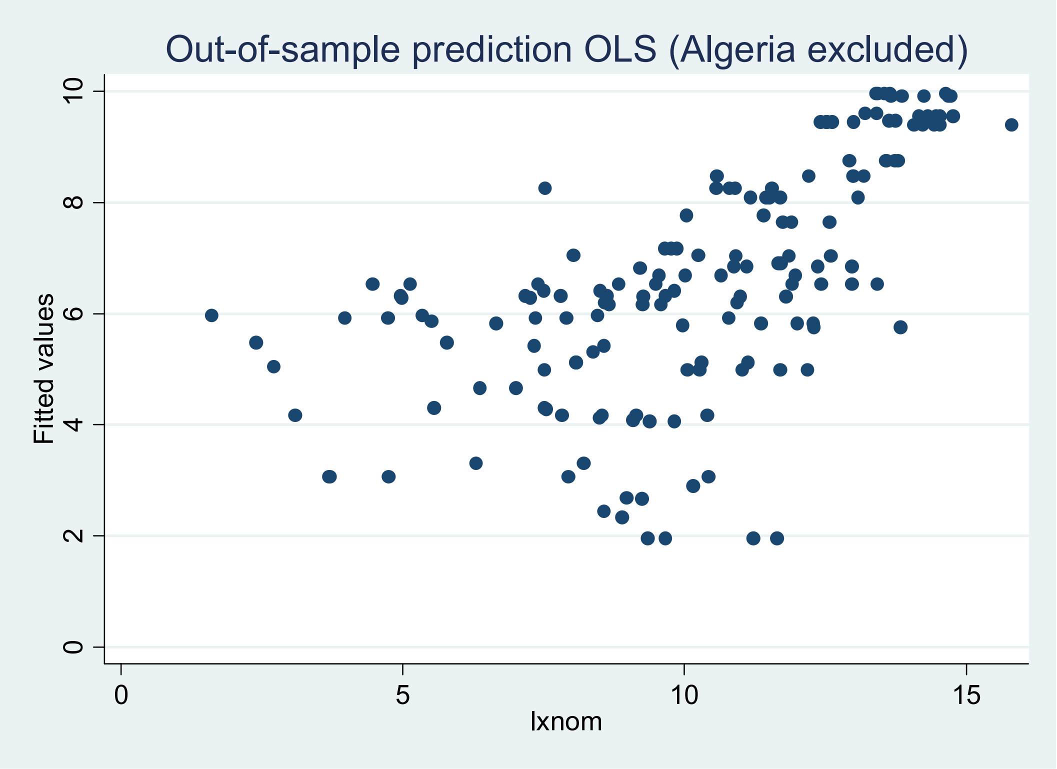
Table 6. Test for the implicit assumption in PPML and OLS/FGLS. Various years.

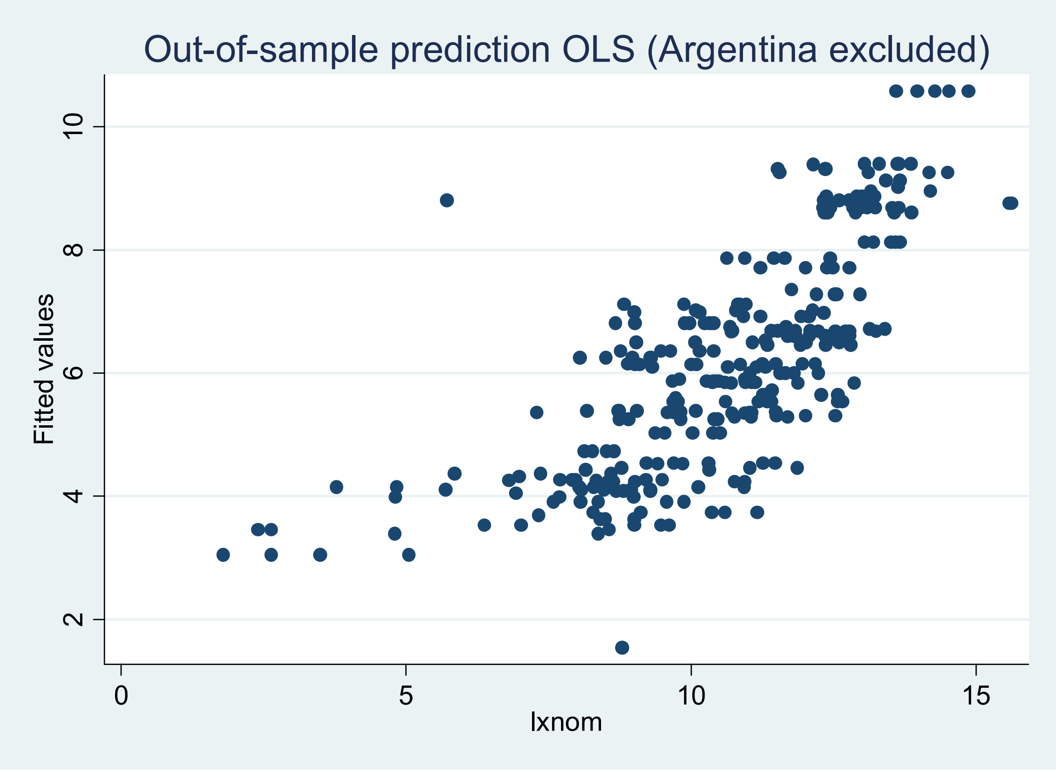
GNR TEST PPML	**1981**	**1990**	**1995**	**2000**
Rose data				
p-value	0.015	0.015	0.016	0.036
Nobs	11852	13974	17616	15110
Park TEST LOG-LOG	**1981**	**1990**	**1995**	**2000**
p-value	0.00	0.00	0.00	0.00
Nobs	10036	12134	15518	11694

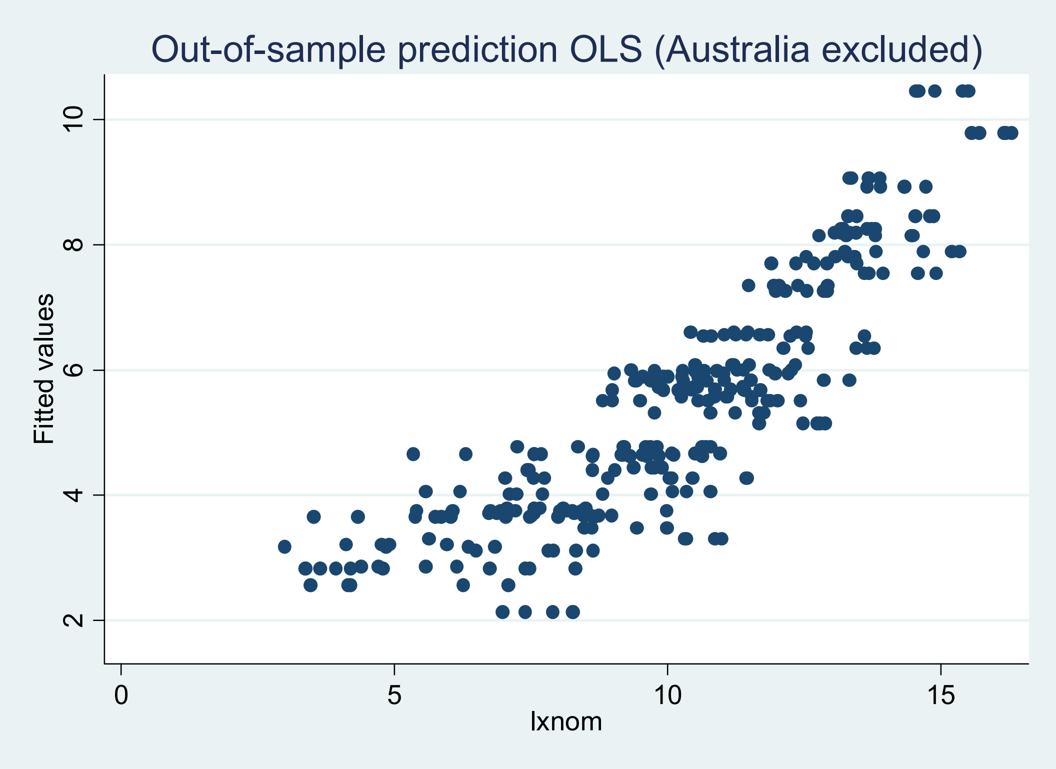
Appendix

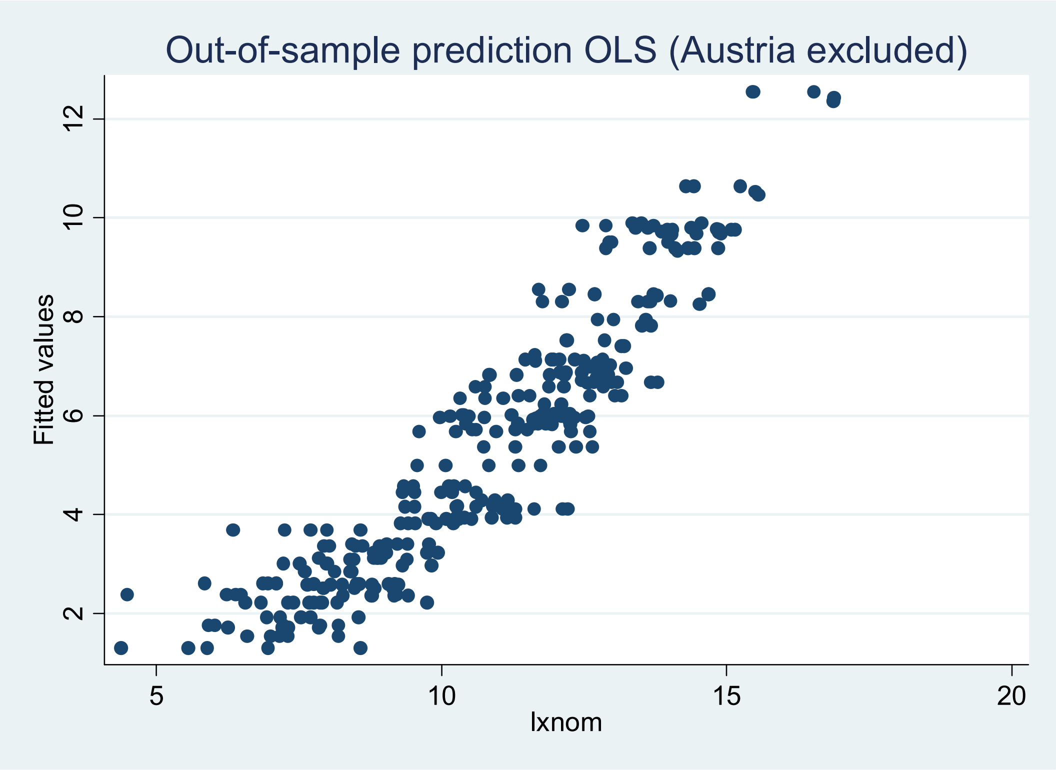
Cross-validation for OLS estimations in year 1990



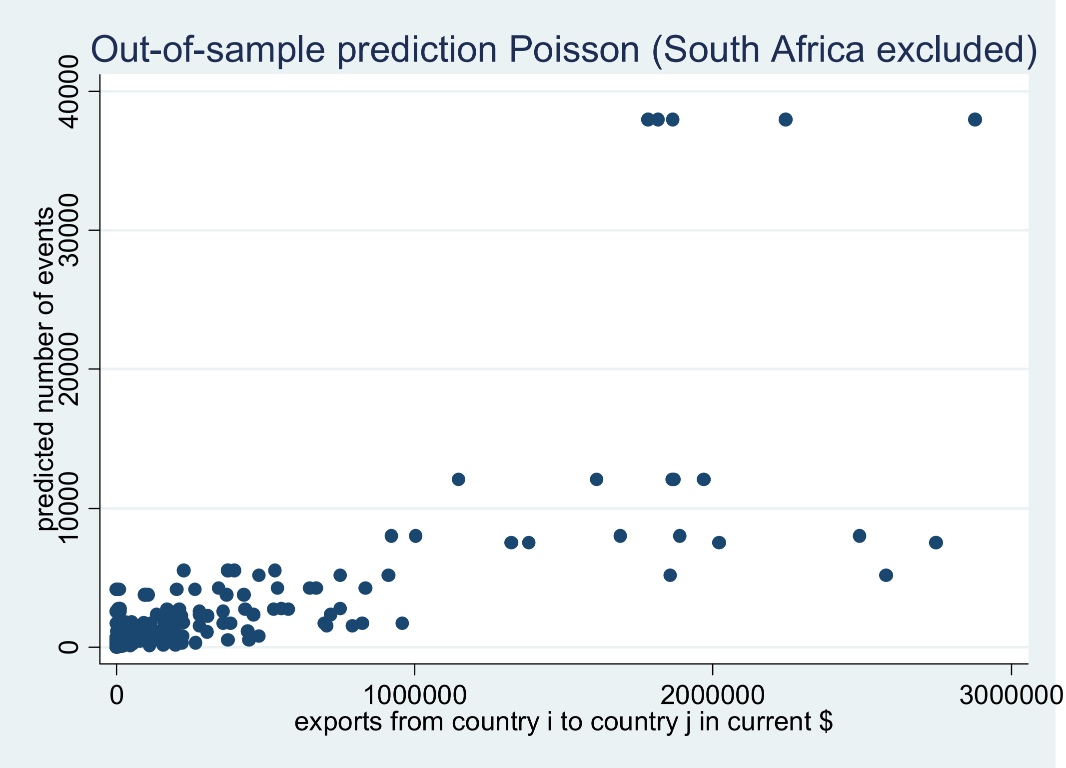


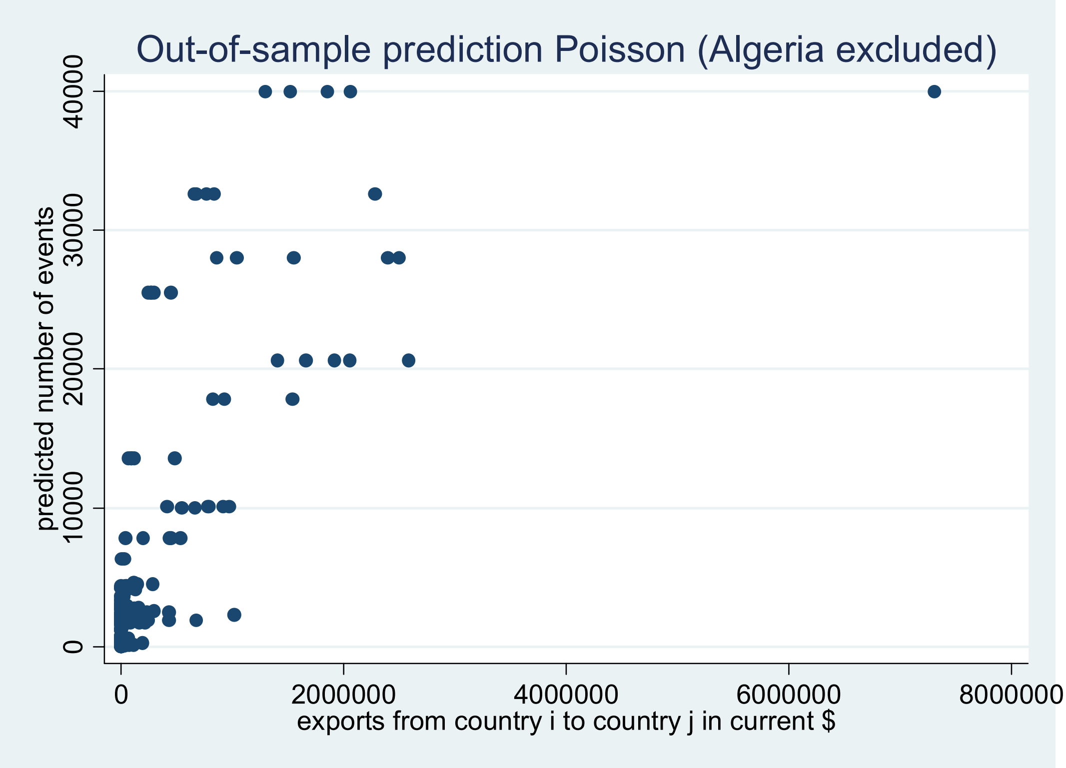

Out-of-sample prediction OLS (Argentina excluded)

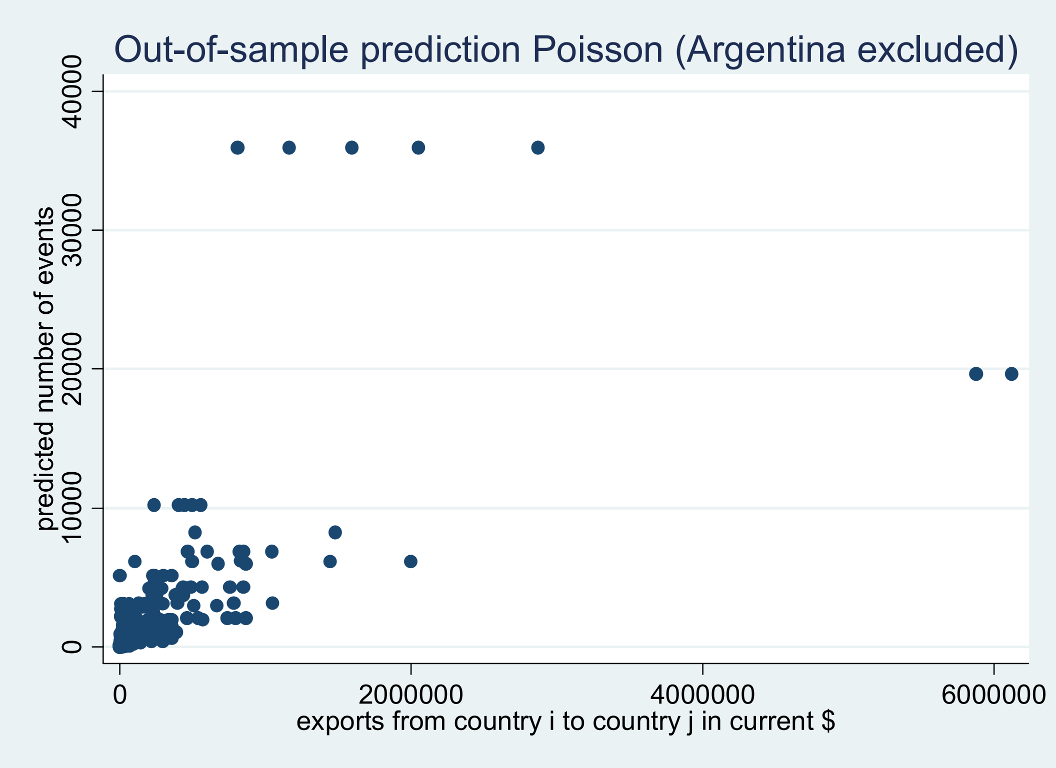

Out-of-sample prediction OLS (Australia excluded)

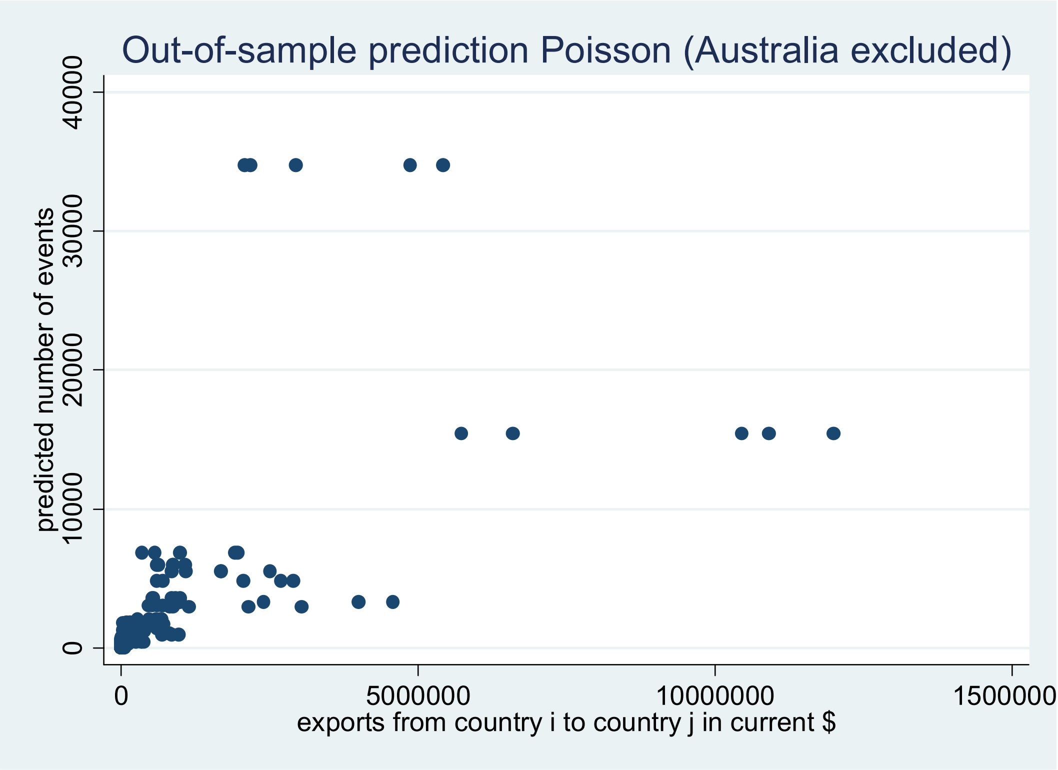


Cross-validation for Poisson estimations in year 1990




Out-of-sample prediction Poisson (Algeria excluded)
predicted number of events
0
10000
20000
30000
40000
0
2000000
4000000
6000000
8000000
exports from country i to country j in current $


Out-of-sample prediction Poisson (Argentina excluded)
predicted number of events
0
10000
20000
30000
40000
0
2000000
4000000
6000000
exports from country i to country j in current $


Out-of-sample prediction Poisson (Australia excluded)
predicted number of events
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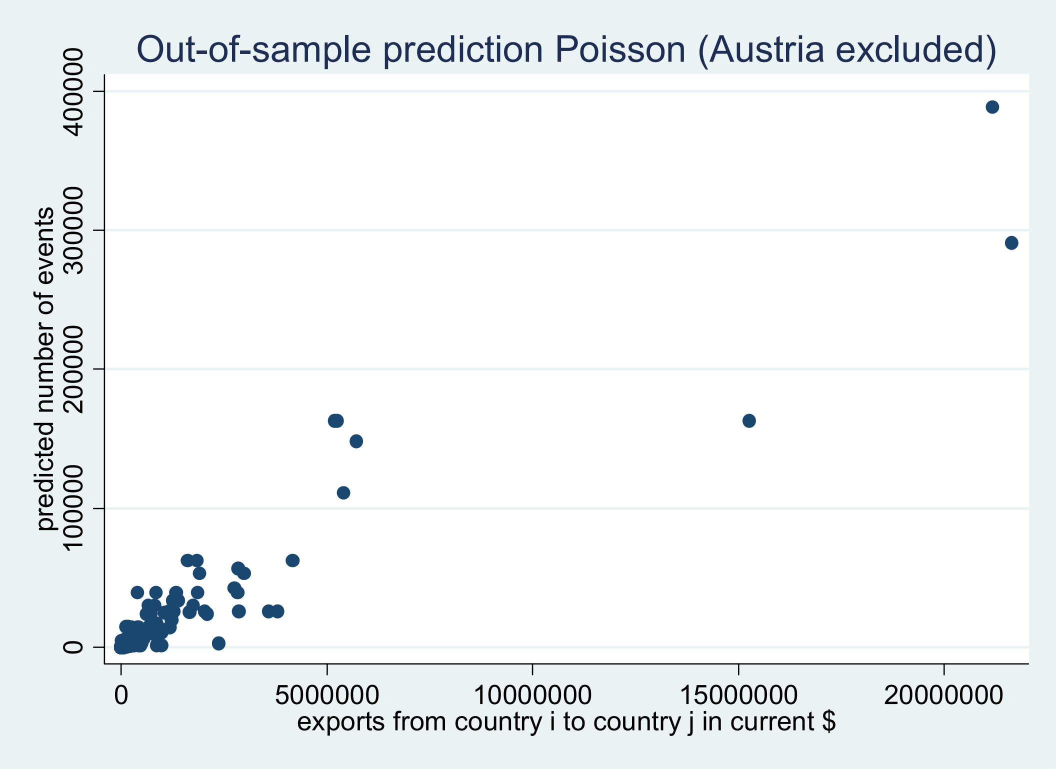
10000
20000
30000
40000
0
5000000
10000000
15000000
exports from country i to country j in current $


Out-of-sample prediction Poisson (Austria excluded)
predicted number of events
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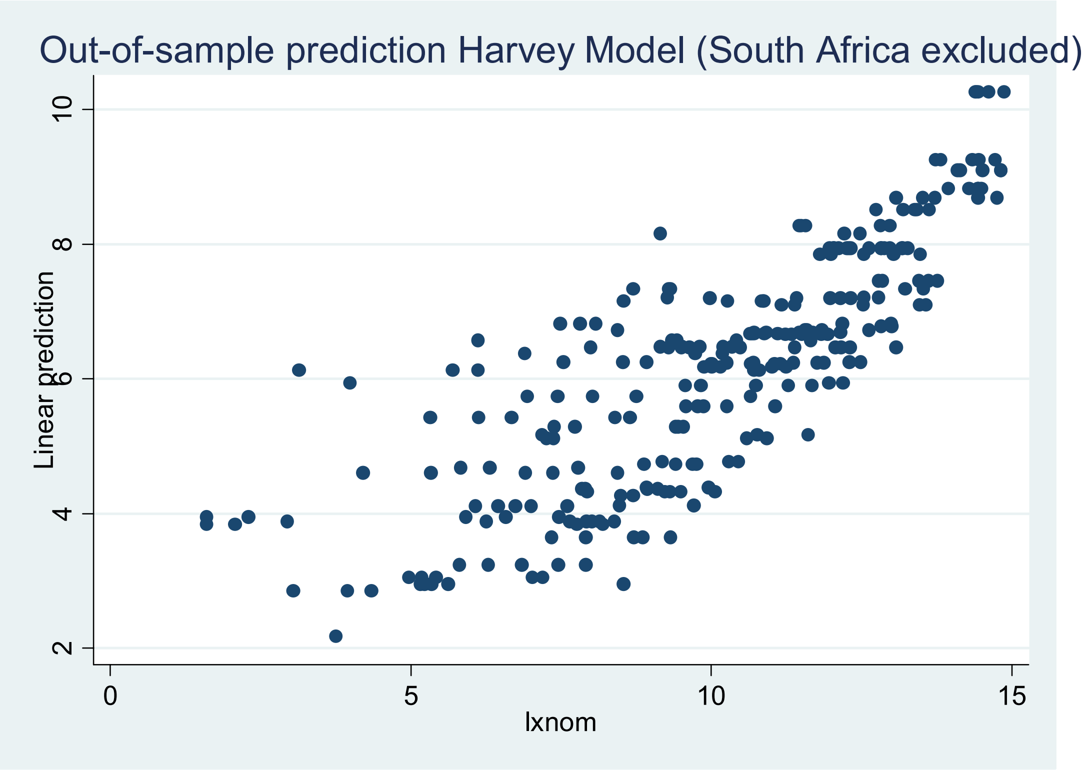
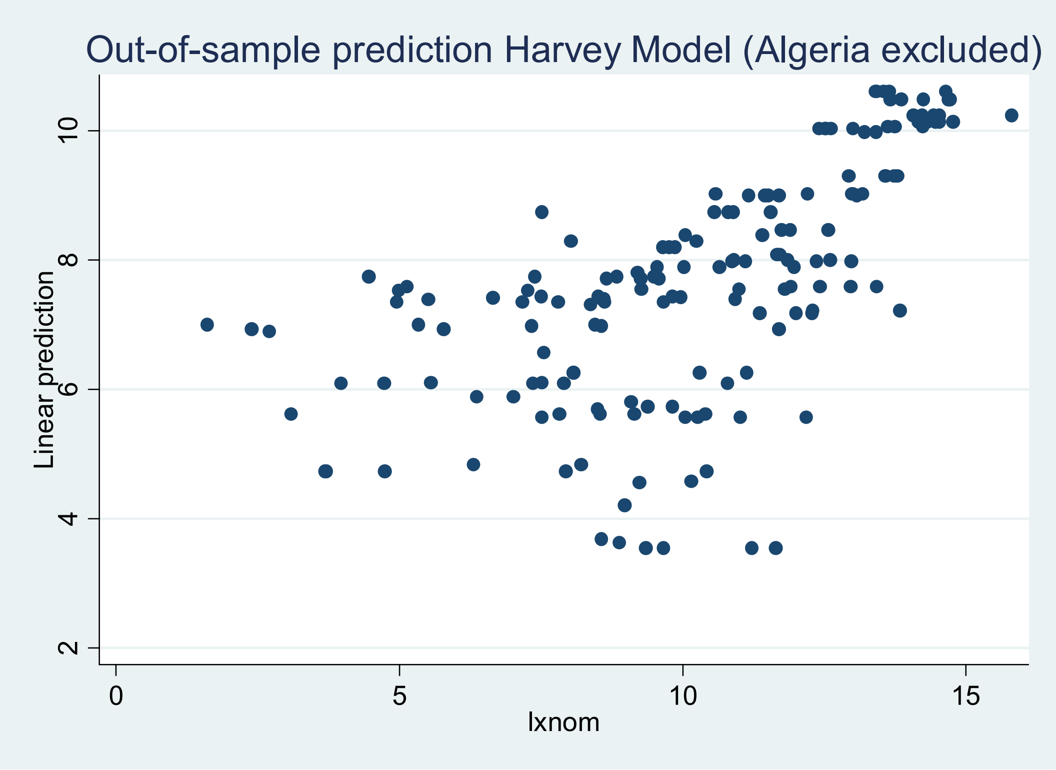
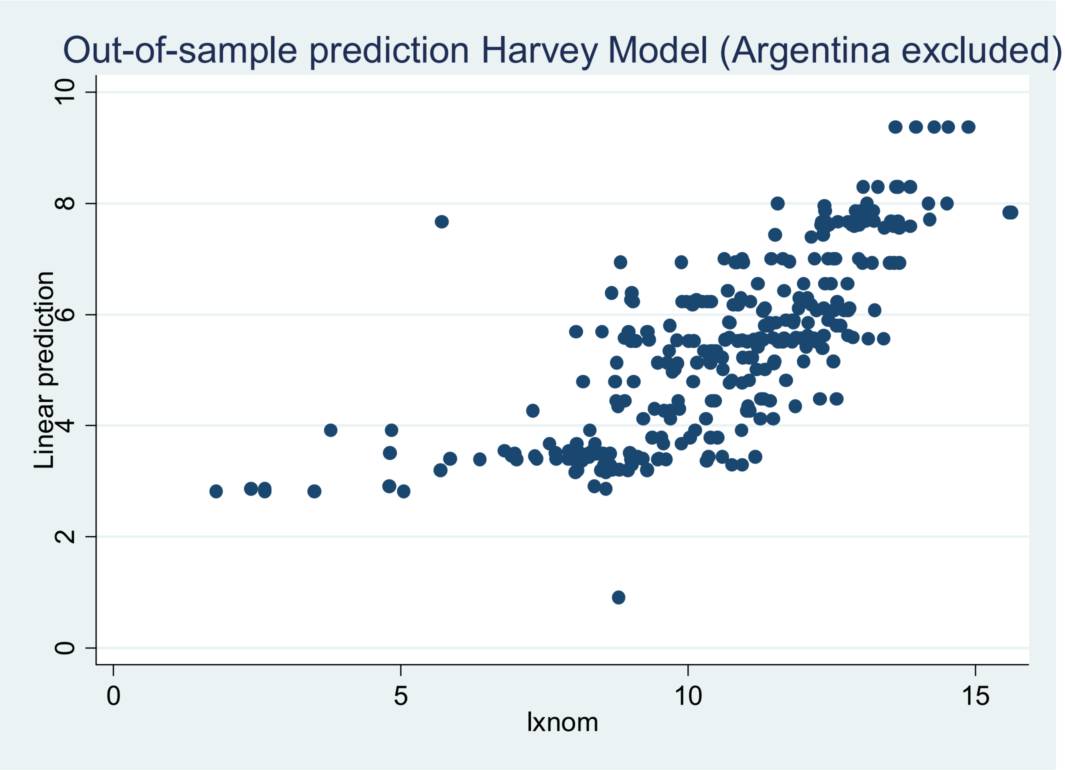
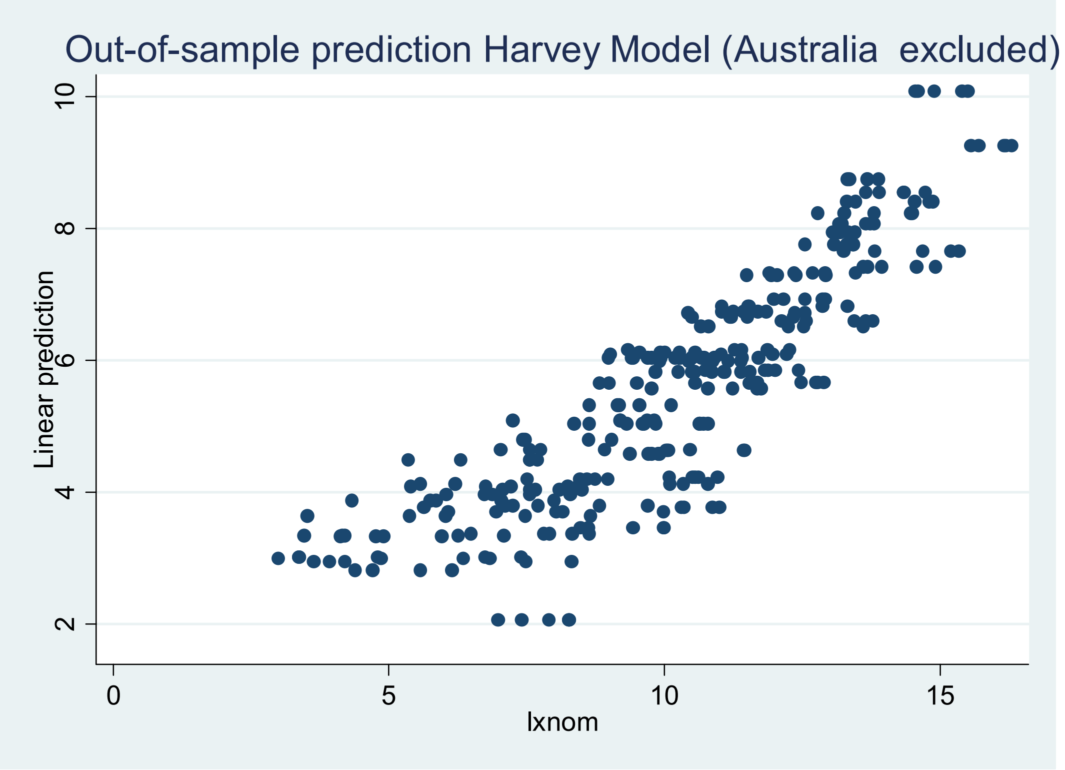
100000
200000
300000
400000
0
5000000
10000000
15000000
20000000
exports from country i to country j in current $


Out-of-sample prediction Harvey Model (South Africa excluded)
Linear prediction
2
4
6
8
10
0
5
10
15
lxnom


Out-of-sample prediction Harvey Model (Algeria excluded)
Linear prediction
2
4
6
8
10
0
5
10
15
lxnom


Out-of-sample prediction Harvey Model (Argentina excluded)
Linear prediction
0
2
4
6
8
10
0
5
10
15
lxnom


Out-of-sample prediction Harvey Model (Australia excluded)
Linear prediction
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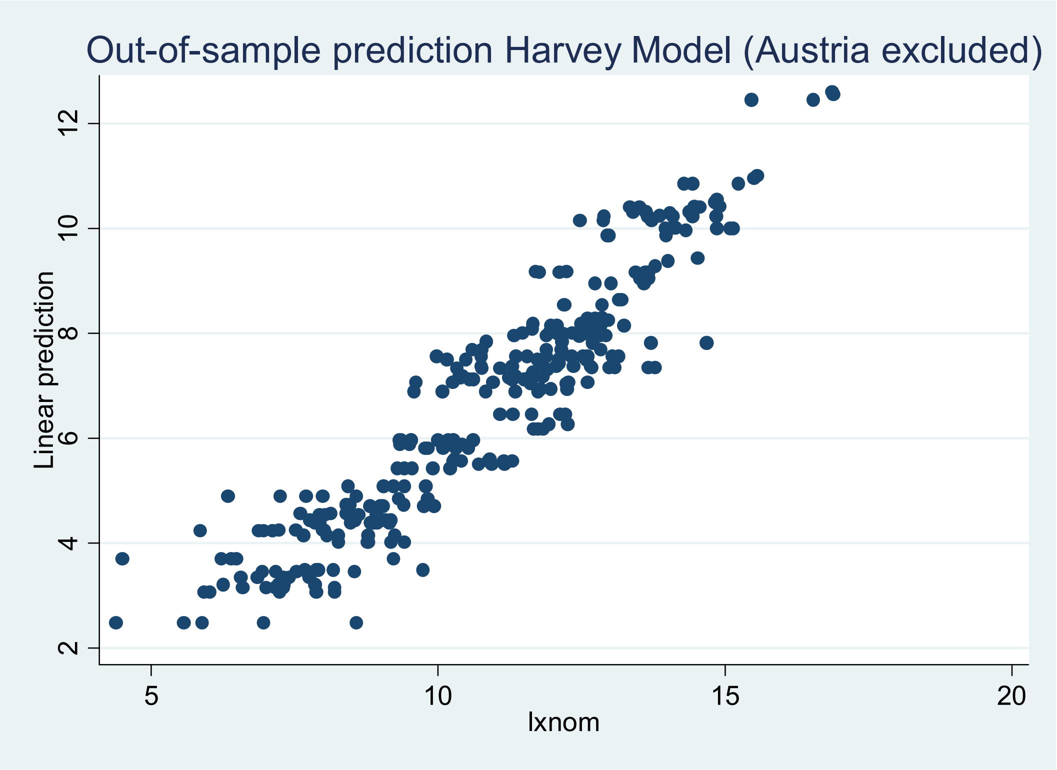
Out-of-sample prediction Harvey Model (Austria excluded)
Linear prediction
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