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The Log of Gravity: An Update to a Report on Seriousness

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Abstract

This paper reproduces a portion of the results found in Silva and Tenreyro (2006), "The Log of Gravity". I have updated the Poisson Psuedo-Maximum Likelihood (PPML) regression method with 2010 data for GDP and GDP per capita, and have added several new free trade accords to the Trade Preference variable. Fourteen countries (about 10% of the original country list) have been selected from the 136 countries illustrated in Silva and Tenreyro (2006). Four differing regressions are performed to test the consistency of the author's results upon this condensed set.

While the results are inconclusive for the updated subset, it can be shown that PPML estimates were similar and the significant variables (with one exception) were consistent. Inversely, the OLS estimates were too noisy and lacked enough consistency for an definitive analysis. This leads to an inability to make considerable conclusions at this time; but the results lead me to believe that further data accumulation will lead to better and more robust estimates.

Table of Contents

1. Issues with the Gravity Equation

Over the past few decades, there has been an unparalleled increase in international trade and interdependence of countries' economies. This interdependency has encouraged economists to explore and better understand the underpinnings of international trade. In the pursuit of understanding, modern literature uses a model that is analogous to Newton's law of gravity, which coincidently is named the gravity equation. Despite the heavy use of the gravity equation, there are biases associated with the model. In exemplum, the majority of scholarly research log transforms the gravity equation and subsequently runs an OLS regression. However in the presence of heteroskedasticity (which appears in the data more often than not) or when the bilateral trade between countries is zero, the results of the OLS regression become suspect.

For this paper I will mainly be focusing on Silva and Tenreyro's (2006) "The Log of Gravity". The authors propose that using the level form of the gravity equation is better since the model will be free of biases caused by truncating the sample due to zero bilateral trade pairs. Moreover, Silva and Tenreyro devise a pseudo-maximum likelihood method that accounts for the inherent heteroskedastic issues. I will first review their data, and I will then conduct the original analysis and the updated analysis respectively.

Modern trade literature tends to use a log form of the gravity equation as the model to be analyzed. Trade volume is defined by:

$$T_{ij} = \alpha_0 Y_i^{\alpha_1} Y_j^{\alpha_2} D_{ij}^{\alpha_3} exp\left(\alpha_4 S_i + \alpha_5 S_j + \alpha_6 \delta_{ij}\right)\varepsilon_{ij}$$

where *Y* is the GDP of country *i* and country *j*, D is the distance between the two economies, s_i and s_j are the barriers of trade for country i and country j, ε is the error term, and the α's are the parameters

that are to be estimated. Following the convention of modern literature, the log of the above gravity equation is performed to obtain the following, and a successive OLS regression is conducted.

$$ln(T_{ij}) = ln(\alpha_0) + \alpha_1 ln(Y_i) + \alpha_2 ln(Y_j) + \alpha_3 ln(D_{ij}) + \alpha_4 S_i + \alpha_5 S_j + \alpha_6 \delta_{ij} + ln(\varepsilon_{ij})$$

Silva and Tenreyro claim that the log-transformed gravity model is subject to four types of estimation bias. These biases could be the originators of the aforementioned controversy. The first source of bias comes from the heteroskedastic nature of the error term (which is the main focus of this paper). Since it is often the case that the level model suffers from heteroskedasticity problems, so then will the log transformed model. The second source of estimation bias is due to the nature of the log transformation. Country pairs with zero trade values will be dropped from the model, effectively truncating the sample. Another source of bias originates from omitted-variable bias. It is standard to assume that exchange rate volatility is exogenous; however, this is seldom true. For instance, two countries looking to increase their relative levels of trade could do so by reducing trade barriers or standardizing production regulations. The final source of bias is from measurement error. There is a large variation between what countries report and what countries actually do.

Silva and Tenreyro (2006) focus specifically on the first two sources of bias: heteroskedasticity and log transformed gravity equations. The authors propose a PPML (Poisson Pseudo-Maximum Likelihood) regression method that compensates for the heteroskedastic nature of the data.[1] To compensate for zero value bilateral trade pairs, the authors use the level form of the gravity equation rather than the log transformed gravity equation. Furthermore, Silva and Tenreyro found, in the robustness checks, that to

[1] The validity and robustness of this method is left to the analysis of the original paper, Silva and Tenreyro (2006).

obtain consistent estimators using the PPML regression, the gravity equation must be in its level form; further perpetuating that the level form should be used.

2. Literature Review

The Gravity Equation was first proposed by Tinbergen (1962) and was later expanded upon by Anderson and Van Wincoop (2003). This model was created to theorize bilateral trade in an international setting. The theory states that international trade between two countries is directly proportional to the relative size of the two countries' GDP and inversely proportional to the distance between them. Three papers which were found to support the Gravity Equation in theoretical foundations are Anderson (1979), Bergstrand (1985), and Anderson and Van Wincoop (2003). Anderson and Wincoop (2003) use cross-sectional data on monopolistic competition and propose a method to estimate gravity coefficients. They conclude that both the relative size of GDP and the distance between two countries are highly significant for bilateral trade. Further, they determine that trade costs directly influence bilateral trade volume.

There are problems associated with the Gravity Equation however. These issues were outlined in Silva and Tenreyro (2006) and later in Tenreyro (2007). Silva and Tenreyro (2006) state that in the presence of heteroskedasticity, the log transformed gravity model suffers from biased estimates. The log transformed model also breaks down in the presence of zero valued bilateral trade volume. The authors then propose a PPML regression method on the level form of the Gravity Equation. In Tenreyro (2007) four potential biases plague the Gravity Equation. These biases must be addressed simultaneously in order to avoid misleading results. It is here that Tenreyro puts forth a PPML-IV method regressed on the level form gravity model. This simultaneously accounts for the aforementioned zero valued trade volume, heteroskedasticity, endogeneity, and measurement error. The results of this paper are that

exchange rate volatility have only marginal effects upon trade volume, and that distance between a client country and an anchor country increases the probability that the client will peg its currency to the anchor.

3. Data

3.1 Original Data Set

Silva and Tenreyro (2006) use cross-sectional data that covers 136 countries in 1990.[2] The variables of interest are trade, country GDP, country GDP per capita, the log of distance, country's remoteness, and openness. The authors also control the following variables using dummies: common borders, common language (first and secondary), colonial ties, if the country is landlocked, and if the country is part of a free trade agreement.

The data for trade, or bilateral exports, comes from Feenstra et al. (1997). The data on real GDP, GDP per capita, and population are found in the World Bank's (2002) World Development Indicators. The CIA *World Factbook* (2002) provides the data for the contiguity, common language, colonial ties, and access to water dummies. Andrew Gray (2001) computes the relative distance of countries. Wei (1996) computes remoteness as the log of GDP as a weighted average of distance to all other countries. Data on preferential trade statuses is arranged by Frankel (1997).

[2] A list of countries is included in Appendix A1.

3.2 Updated Data Set

The updated data contains 14 randomly selected countries from Silva and Tenreyro's original sample of 136 countries.[4] Each of these 14 countries contains updated data for real GDP, real GDP per capita, and favorable trade agreements. The real GDP and real GDP per capita data utilized in my research is the 2010 statistics from the December update for the World Bank's (2011) *World Development Indicators*. The list of favorable trade agreements and their respective member nations were taken from their respective hosted websites[6]. All other time-invariant data were taken from Silva and Tenreyro's data set; these variables include: distance, contiguity, common language, colonial ties, landlocked, and remoteness.

The bilateral trade variable was also taken from the Silva and Tenreyro (2006) data set, but was updated to 2010 values in order to streamline the results. Bilateral trade was updated via multiplication of an inflation coefficient calculated by the average annual inflation over the last twenty years to account for the 1990 to 2010 update. The inflation coefficient was found through the Saint Louis Federal Reserve website (FRED).[7]

[4] The 14 randomly chosen countries constitute approximately 10% of the original sample of countries. A listing of these countries can be found in Appendix A2.
[6] This updated data is also from 2010. A list can be found in Appendix A4.
[7] The FRED estimated the inflation coefficient over this time period to be 66.56% as calculated through the CPI.

4. Original Data Analysis

In this section I reproduce sections of Table 3 in Silva and Tenreyro (2006).[8] I ran two OLS regressions and two regressions that utilize the PPML method, accounting for heteroskedasticity. The first OLS regression emulates the current standard log transformed gravity equation; thus the dependant variable is *ln(trade).* This regression removes all bilateral trade pairs that have zero trade from the data, effectively truncating the sample.

The second regression is still the standard OLS log transformed regression, but compensates for the zero bilateral trade pairs. The value of 1 is added to all trade values and the log transformed dependent variable is *ln(1 + trade).* As a result of this transformation, no observations are dropped or removed from the data.

The third and fourth model uses the level form of the gravity equation utilizing the PPML regression. The difference is that regression three only uses values of trade that are greater than 0, while regression four uses the entire sample.

[8] Refer to Table 3, Silva and Tenreyro (2006) "The Log of Gravity", *The Review of Economics and Statistics,* page 650.

Table 1 - reproduction of Silva and Tenreyro's results:

Estimator:	OLS	OLS	PPML	PPML
Dependent Variable:	$\boldsymbol{ln(T_{ij})}$	$\boldsymbol{ln(1+T_{ij})}$	$\boldsymbol{T_{ij}>0}$	$\boldsymbol{T_{ij}}$
Log Exporter's GDP	0.938**	1.128**	0.721**	0.732**
	(0.012)	(0.011)	(0.027)	(0.027)
Log Importer's GDP	0.798**	0.866**	0.732**	0.741**
	(0.011)	(0.011)	(0.028)	(0.027)
Log Exporter's GDP per capita	0.207**	0.277**	0.154**	0.157**
	(0.017)	(0.017)	(0.053)	(0.053)
Log Importer's GDP per capita	0.106**	0.217**	0.133**	0.135**
	(0.017)	(0.017)	(0.044)	(0.045)
Log Distance	-1.166**	-1.151**	-0.776**	-0.784**
	(0.034)	(0.037)	(0.055)	(0.055)
Contiguity Dummy	0.314*	-0.241	0.202	0.193
	(0.143)	(0.164)	(0.105)	(0.104)
Common-Language Dummy	0.678**	0.742**	0.751**	0.746**
	(0.064)	(0.064)	(0.134)	(0.135)
Colonial-Tie Dummy	0.397**	0.392**	0.012	0.025
	(0.068)	(0.068)	(0.150)	(0.150)
Landlocked-Exporter Dummy	-0.062	0.106*	-0.872**	-0.863**
	(0.065)	(0.060)	(0.157)	(0.157)
Landlocked-Importer Dummy	-0.665**	-0.278**	-0.703**	-0.696**
	(0.063)	(0.060)	(0.141)	0.141
Exporter's Remoteness	0.467**	0.526**	0.647**	0.660**
	(0.078)	(0.089)	(0.135)	(0.134)
Importer's Remoteness	-0.205**	-0.109	0.549**	0.562**
	(0.081)	(0.089)	(0.120)	(0.119)
Free-Trade Agreement Dummy	0.491**	1.289**	0.179*	0.181*
	(0.105)	(0.143)	(0.090)	(0.089)
Openness	-0.170**	0.739**	-0.139	-0.107
	(0.049)	(0.048)	(0.133)	(0.131)
Observations	**9613**	**18360**	**9613**	**18360**
RESET test p-values	**0.000**	**0.000**	**0.941**	**0.332**

The replicated results generally equal the results from the original paper. The only discrepancies that appear are in the third or fourth significant digit; thus any difference becomes negligible.

For a full analysis refer to Silva and Tenreyro (2006). The main result to be noted from the above table is that it is heteroskedasticity, not truncation of the data, that is the cause of the apparent differences. Notice that the estimated coefficients for both PPML regressions are nearly identical, with only minor

variation. When we compare this to both OLS regressions, we see significant differences in the estimates. A secondary result is that the OLS tends to have over-exaggerated the estimates of real GDP for imports and exports, log distance, and colonial ties. Finally, the RESET Test favors the PPML methods over the OLS method, illustrated in the test's p-values located at the bottom of Table 1.

5. Analysis with Updated Data

This section follows the same format previously outlined but with the condensed 14 country subset 2010 data. The expected results are four-fold in response. First, are the PPML estimated coefficients similar in value? Second, are the estimates for the log of GDP for importer and exporter small for the PPML? Third, are the values for log of distance and colonial-ties over-exaggerated for the OLS regressions? Finally, fourth, does the RESET test favor the PPML method? The results of the updated regressions can be found in Table 2.

Table 2 - Results using the updated data subset.

Estimator:	OLS	OLS	PPML	PPML
Dependent Variable:	$\boldsymbol{ln(T_{ij})}$	$\boldsymbol{ln(1+T_{ij})}$	$\boldsymbol{T_{ij}>0}$	$\boldsymbol{T_{ij}}$
Log Exporter's GDP	0.806**	1.212**	0.888**	1.022**
	(0.148)	(0.144)	(0.166)	(0.216)
Log Importer's GDP	0.799**	0.869**	0.640**	0.826**
	(0.139)	(0.144)	(0.082)	(0.133)
Log Exporter's GDP per capita	0.464*	0.328	-0.016	-0.236
	(0.207)	(0.208)	(0.205)	(0.251)
Log Importer's GDP per capita	0.227*	0.561**	0.378**	0.107
	(0.208)	(0.207)	(0.143)	(0.178)
Log Distance	-1.769**	-0.041	-2.398**	-1.943**
	(0.507)	(0.452)	(0.413)	(0.405)
Contiguity Dummy	(Omitted)	-0.774	(dropped)	(dropped)
		(1.077)		
Common-Language Dummy	-0.370	2.364**	-0.815	-0.412
	(0.709)	(0.842)	(0.591)	(0.644)
Colonial-Tie Dummy	0.334	-2.139**	-0.206	-0.917
	(0.798)	(0.834)	(0.663)	(0.644)
Landlocked-Exporter Dummy	0.949	0.838	-1.243	-0.923
	(0.574)	(0.543)	(0.730)	(0.735)
Landlocked-Importer Dummy	-0.502	0.492	-0.671	-0.373
	(0.590)	(0.543)	(0.438)	(0.432)
Exporter's Remoteness	3.481**	0.807	3.219**	3.018**
	(1.307)	(1.502)	(0.828)	(0.995)
Importer's Remoteness	0.163	-0.518	-0.092	-0.299
	(1.306)	(1.501)	(0.782)	(0.995)
Free-Trade Agreement Dummy	-2.969	0.041	-5.365**	-4.683**
	(1.494)	(0.971)	(1.479)	(0.845)
Openness	-0.333	0.119	-0.010	0.367
	(0.511)	(0.504)	(0.417)	(0.572)
Observations	**72**	**182**	**72**	**172**
RESET test p-values	**0.259**	**0.000**	**0.005**	**0.140**

Unfortunately the answers to the above four questions are not as obvious as the results found in Silva and Tenreyro (2006). In comparison to the Silva and Tenreyro results, the PPML estimates are no longer as close in value, but neither are the values too divergent. The two estimates that vary the most are the colonial-ties dummy and the common language dummy. Diversely, reviewing the OLS regression estimates, the difference in values can vary wildly and dramatically.

When comparing the estimates of log GDP for imports and exports, between the OLS and PPML regression, it is no longer clear if one estimating method overvalues or undervalues the estimate. The same is true for the proximity variable and the colonial ties dummy.

Finally the RESET test also shows a degree of ambiguity. The RESET test favors the OLS regression with truncated trade values and the PPML regression using all trade values.[9] Conversely, the RESET test states that the OLS regression (with modified positive trade values) and the PPML method (using only positive trade values) can be improved using a linear fit variable.

There are three apparent problems that need to be addressed before the above results can be safely interpreted. The first problem is that the updated set only includes 10% of the original samples countries. In Silva and Tenreyro (2006) the data set contains 136 countries which calculates to (136*135) 18,360 data points. The above data set only has 14 countries, or 186 bilateral trade data points. So decreasing the amount of countries to 14 reduces the sample size by about 18,180 data points. There is a vast amount of information missing that may be causing a bias to the results. A second problem is losing the common border dummy. Out of the 14 randomly chosen countries, only two share a border. Consequently, almost all of the contiguity dummy entries are zero. Thus any effect that sharing a border has, in this subset analysis, is lost. The final issue is that only GDP, GDP per capita, and preferential trade agreements have been updated to 2010 values. For the analysis to stand up to robustness checks bilateral trade levels and the openness values need to also be updated to 2010 values. I did change the bilateral trade values from 1990 dollars to 2010 dollars but this effect proved negligible in correcting the model.

[9] Including zero bilateral trade values.

6. Conclusions

As it stands, the updated results are ambiguous at best. None of the four main Silva and Tenreyro (2006) results could be verified with this condensed subset. The PPML estimates for both models were not close enough in value to make the claim that it is heteroskedastic bias, not truncation, that fuels the differences. I could also not claim that the OLS models overstate the importance of real GDP, real GDP per capita, and the colonial-ties dummy. Finally, the RESET test was not consistent in determining which regression type is favored.

Despite these inconclusive results, much work needs to be done before any decisive results can drawn. For further research and analysis, the updated 2010 data needs to be expanded to all 136 countries and bilateral trade data for 2010 needs to be tabulated. My updated information is only estimating lagged values of trade and the importance of this model is dubious. A richer, more robust model, must have all variables calculated in 2010 and then regressed using both OLS and PPML methods. It is at this point that true conclusions could be drawn.

7. Appendices

Appendix A1 - Silva and Tenreyro (2006) country list

Albania	Denmark	Kenya	Romania
Algeria	Djibouti	Kiribati	Russian Federation
Angola	Dominican Rep.	Korea, Rep.	Rwanda
Argentina	Ecuador	Laos P. Dem. Rep.	Saudi Arabia
Australia	Egypt	Lebanon	Senegal
Austria	El Salvador	Madagascar	Seychelles
Bahamas	Eq. Guinea	Malawi	Sierra Leone
Bahrain	Ethiopia	Malaysia	Singapore
Bangladesh	Fiji	Maldives	Solomon Islands
Barbados	Finland	Mali	South Africa
Belgium-Lux	France	Malta	Spain
Belize	Gabon	Mauritania	Sri Lanka
Benin	Gambia	Mauritius	St. Kitts and Nevis
Bhutan	Germany	Mexico	Sudan
Bolivia	Ghana	Mongolia	Suriname
Brazil	Greece	Morocco	Sweden
Brunei	Guatemala	Mozambique	Switzerland
Bulgaria	Guinea	Nepal	Syrian Arab Rep.
Burkina Faso	Guinea-Bissau	Netherlands	Tanzania
Burundi	Guyana	New Caledonia	Thailand
Cambodia	Haiti	New Zealand	Togo
Cameroon	Honduras	Nicaragua	Trinidad and Tobago
Canada	Hong Kong	Niger	Tunisia
Central Africa Rep.	Hungary	Nigeria	Turkey
Chad	Iceland	Norway	Uganda
Chile	India	Oman	United Arab Em.
China	Indonesia	Pakistan	United Kingdom
Colombia	Iran	Panama	United States
Comoros	Ireland	Papua New guinea	Uruguay
Congo Dem. Rep.	Israel	Paraguay	Venezuela
Congo Rep.	Italy	Peru	Vietnam
Costa Rica	Jamaica	Philippines	Yemen
Ivory Coast	Japan	Poland	Zambia
Cyprus	Jordan	Portugal	Zimbabwe

Appendix A2 - Updated subsample country list

Belize	Nigeria	Niger
Mali	Gabon	Dominican Rep.
Malawi	Pakistan	Madagascar
Japan	Honduras	Guinea
Spain	Burkina Faso	

Appendix A3 - List of Preferential Trade Agreements

EEC/EC	**CARICOM**	**CACM**
Belgium	Bahamas	Costa Rica
Denmark	Barbados	El Salvador
France	Belize	Guatemala
Germany	Dominican Rep.	Honduras
Greece	Guyana	Nicaragua
Ireland	Haiti	
Italy	Jamaica	**Bilateral Agreements**
Luxembourg	Trinidad and Tobago	
Netherlands	St. Kitts and Nevis	EC-Cyprus
Portugal	Suriname	EC-Malta
Spain		EC-Egypt
United Kingdom	**SPARTECA**	EC-Syria
		EC-Algeria
EFTA	Australia	EC-Norway
	New Zealand	EC-Iceland
Iceland	Fiji	EC-Switzerland
Norway	Kiribati	Canada-United States
Switzerland	Papua New Guinea	Israel-United States
Liechtenstein	Solomon Islands	
CER	**PATCRA**	
Australia	Australia	
New Zealand	Papua New Guinea	

Appendix A4 - Updated List of Preferential Trade Agreements

EFTA - European Free Trade Association

Iceland
Liechtenstein
Norway
Switzerland

CER - Closer Economic Relations

Australia
New Zealand

CARICOM - Caribbean Community

Antigua and Bermuda
Bahamas
barbados
Belize
Domincan Rep.
Grenada
Guyana
Haiti
Jamaica
Montserrat
Saint Kitts and Nevis
Saint Lucia
Saint Vincent & Grenadines
Suriname
Trinidad and Tobago

SPARTECA - South Pacific Regional Trade and Economic Co-operation Agreement

Cook Isle.
Australia
Fiji
Marshal Isle.
Micronesia
Nauru
New Zealand
Papua New Guinea
Samoa
Solomon Isle.
Tonga
Tuvalu
Vanuatu
Kiribati
Niue

PATCRA - Papua New Guinea-Australia Trade and Commercial Agreement

Australia
Papua New Guinea

CACM - Central American Common Market

Belize
Costa Rica
El Salvador
Guatamala
Honduras
Nicaragua
Panama
Dominican Rep.

EU - European Union

Austria
Belgium
Bulgaria
Cyprus
Czech Rep.
Germany
Greece
Hungary
Ireland
Italy
Netherlands
Poland
Portugal
Romania
Slovakia

Denmark
Estonia
Finland
France
Latvia
Lithuania
Luxembourg
Malta
Slovenia
Spain
Sweden
United Kingdom

NAFTA - North American Free Trade Agreement

Canada
Mexico
United States

ASEAN - Association of Southeastern Asian Nations

Brunei
Cambodia
Indonesia
Laos
Malaysia
Philippines
Singapore
Thailand
Vietnam

BRICS

Brazil
China
India
Russia
South Africa

ECOWAS - Economic Community of West African States

Benin
Burkina Faso
Cape Verde
Cote d'Ivoire
Gambia
Ghana
Guinea
Guinea-Bissau
Liberia
Mali
Niger
Nigeria
Senegal
Sierra Leone
Togo

EAC - East African Community

Burundi
Kenya
Rwanda
Tanzania
Uganda

CEN-SAD - Community of Sahel-Saharan States

Burkina Faso
Chad
Libya
Mali
Niger
Sudan
Central African Rep.
Eritrea
Djibouti
Gambia
Senegal
Egypt
Morocco
Nigeria
Somalia
Tunisia
Burundi
Togo
Cote d'Ivoire
Guinea-Bissau
Liberia
Ghana
Sierra Leone
Comoros
Guinea
Kenya
Mauritania
Sao Tome and Principe

COMESA - Common Market for Eastern and Southern Africa

Burundi
Comoros
DRC
Djibouti
Egypt
Eritrea
Ethiopia
Kenya
Libya
Madagascar
Malawi
Mauritius
Rwanda
Seychelles
South Sudan
Swaziland
Uganda
Zambia
Zimbabwe

SADC - Southern African Development Community

Angola
Botswana
DRC
Lesotho
Malawi
Mauritius
Mozambique
Namibia
Seychelles
South Africa
Swaziland
Tanzania
Zambia
Zimbabwe

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