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Revisiting the Effect of Regional Integration on African Trade: Evidence from Meta-Analysis and Gravity Model

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Abstract

Two main shortcomings flaw the estimation of gravity model in previous studies that examined the trade-creating effects of African regional Trade Agreements (RTAs). First, these studies fail to account for the multilateral resistance term (MRT). This omission makes the estimates from standard gravity model bias and inconsistent. Second, there is a significant proportion of zero trade flows, however, these studies also fail to account for them properly. They use either the Tobit model or replace zero flows with arbitrary small values. Apart from these problems, they also exhibit considerable heterogeneity in the RTA effects on trade. In this paper, a meta-analysis of previous empirical studies is conducted to derive a combined effect size and also explain heterogeneity in RTA effects. In addition, I use the gravity model to compare the trade-creating effect of the main African RTAs. Using the gravity model, I compare the estimation methods of previous studies to the Poisson pseudo-maximum-likelihood estimator that tackles the zero flows. From the meta-analysis, I find a general positive effect of African RTAs of about 27-32% after correcting for publication bias. The source of upward bias is not limited to publication selection as the RTA effects tend to be significantly overestimated when zero flows and MRT are not controlled for properly. A comparative assessment of the RTAs shows a striking heterogeneity.

Keywords

Africa, Regional Integration, Trade, Meta-Analysis, Gravity Model.

JEL Codes: C33, F15, O55

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1. Introduction

Regional Trade Agreements (RTAs) have become a significant part of the world trading systems. Africa has also witnessed spiraling initiatives towards economic integration; the rising wave of regionalism has prompted many empirical studies on the effectiveness of such schemes. Until 2000, studies did not reach a consensus on the effectiveness of different economic integration schemes on bilateral trade, even in the case of advanced RTAs (EU or NAFTA). For instance, Aitken (1973), Abrams (1980) and Brada and Mendez (1985) all agree on the significant positive impact of the EU on bilateral trade in contrast to Bergstrand (1985) and Frankel *et al.* (1995). Subsequently, more studies re-assess these RTAs and conclude a robust significant positive impact on bilateral trade after accounting for major econometric concerns within the gravity model (see for exmaple: Baier *et al.*, 2008; Siliverstovs and Schumacher, 2009; Martinez-Zarzoso, 2013). Exhaustively, Cipollina and Salvatici (2010), and Head and Mayer (2014), conducting a meta-analysis, reject the hypothesis that these advanced RTAs do not contribute significantly to trade.

Theoretically, African RTAs are not expected to contribute significantly to bilateral trade because of similar comparative advantage or supply structures (Yang and Gupta 2005). However, the new trade theory indicates that there is a rationale for trade between similar countries, taking the form of intra-industry trade (Feenstra, 2004). In the case of Africa, this may invlove the cross-border trade of simple manufactures or varieties of agricultural commodity.[1] However, the trade–creating effect of African RTAs is still a matter of debate for both reseachers and policy-makers in and outside the region.

Empirically, previous studies that focused on the trade-creating effects of African RTAs have produced varied and diverse results. The variations are in three dimensions: (1) the sign of the coefficient of African RTAs on bilateral trade - whether they are positive or negative, (2) the size - the magnitude of coefficients and (3) the statistical significance of the estimated coefficients. Although, these studies produce mixed outcomes, the majority find large economic and statistically significant impact of these regional blocs on bilater al trade. This contradicts the stylized fact of low intra-African trade, which constitutes less than 15% of total African trade. More importantly, a similar re-assessment has not been carried out on African RTAs, taking into account the econometric concerns as in the case of advanced RTAs. The two main econometric concerns are multilateral resistance term (MRT) and zero flows.

[1]I use regional economic blocs and RTAs interchangeably. African RTAs are referred to as community or regional economic blocs and their objectives go beyond simply trade liberalization. See Table A1 in Appendix 1 for description of the regional blocs and their main objectives.

The MRT is a relevant determinant of bilateral trade. It captures the fact that trade between two countries is not influenced only by bilateral variables relating to these two countries, but also by their relative position in the world (see for example: Anderson and van Wincoop, 2003). This omission results in biased estimates due to possible endogeneity and most of these previous studies fail to account for MRT. The second concern of zero flows is the link to the measurement of trade flows. Trade flow measurement between developing countries (Africa) is characterized by a considerable number of zero flows, mostly arising from missing data and (or) small value trade flows. Longo and Sekkat (2004) put the percentage of zero flows in African bilateral trade around 25%. However, the proportion of zero flows becomes extreme and alarming when we consider trade flows between African countries over long time series. This study is one such case, as the proportion of zero flows is 55%.

Previous studies account for these zero flows by using these strategies; (1) simply omitting the zero values, (2) replacing them with arbitrary small values and (3) using the Tobit estimator. Santos Silva and Tenreyro (2006) label these strategies as infeasible and that they produce inconsistent parameters. Santos Silva and Tenreyro (hereafter SST) point out that Poisson pseudo-maximum-likelihood (PPML) is a better alternative to linear logarithmic transformation of multiplicative models. The PPML estimator has been confirmed by other studies as both consistent in the presence of heteroskedasticity and well-behaved, when the proportion of zero flows is large (SST, 2011; Martínez-Zarzoso, 2013).

Thus, this paper focuses specifically on providing a thorough re-evaluation of the trade-creating effects of African RTAs. It tackles the issue in a twofold manner. First, it uses meta-analysis to assess both how these econometric concerns affect estimates of previous empirical studies and to determine a general combined effect size of these previous studies after accounting for publication bias. Second, it estimates the gravity model using the state-of-art method proposed by SST (2006) for five main RTAs and compares it with the estimation methods employed by the previous studies. By so doing, I examine the sensitivity of the estimates to these different econometric methods. The results show an average impact of African RTAs of 27%, thus indicating that export flow is 27-32% higher for African countries that share membership in the same regional bloc compared to countries that do not. This confirms that the failure of previous studies to account for the econometric concerns of zero flows and MRT leads to an upward bias in RTAs' effect.

The remainder of the paper is organized as follows: Section 2 provides empirical perspectives on African economic integration. Section 3 discusses the data and their sources. Section 4 focuses on the empirical strategies, the meta-analysis and the gravity model, and it also provides and discusses the results. Section 5 concludes the study.

2. Empirical Perspectives on African Integration

Previous empirical studies that focus on assessing the impact of African RTAs have simply produced mixed results , as in the case of previous studies of the EU or NAFTA . The diversity in the results may depend on several factors, such as the specification of the model, estimation methods, the regional blocs being studied, and how the econometric issues such as the MRT and zero flows are dealt with. Additionally, characteristics of the studies – such as their quality, whether the study is published or not, type of data, the sample size (list of countries) and time period of the data – may also to a large extent affect the results. On the basis of the estimation methods of the gravity model, I divide the previous studies into three different groups.

The first group consists of studies by Deme (1995), Cernat (2001) and Musila (2005), relies extensively on the OLS estimation method and fails to account for zero flows. However, the traditional OLS estimation of the gravity model produces biased estimates. This is because, it makes restrictive assumptions by considering that the slopes are the same, irrespective of the time and trading partners (Cheng and Wall, 2005). OLS fails to control for unobserved time-invariant heterogeneity. This is inappropriate as it introduces endogeneity into the model through possible omission of unobserved time-invariant variables such as political, ethnic, cultural and historic factors that can affect bilateral trade.

The second group includes studies by Carrere (2004) and Afesorgbor and Bergeijk (2011). These studies correctly use the FE estimator but eclude the zero flows in the data set. This introduces a selection bias as country-pairs with zero flows are excluded. The exclusion of zero flows leads to an upward bias in the coefficient of bilateral variables (Helpman *et al.,* 2008). An observable trend in the results of the first and second groups is that the regional blocs have a strong significant effect on intra-regional trade but very large magnitudes. For instance, these studies predict magnitudes ranging from 172 to 1000%.

The third group of studies consists of Foroutan and Pritchett (1993), Elbadawi (1997), Longo and Sekkat (2004), Kirkpatrick and Watanabe (2005), and Geda and Kebret (2008). In an attempt to account for zero flows they use the Tobit estimator (TE) or replace the zero flows with arbitrary small values. Incidentally, these studies are the most cited papers with regard to African RTAs. A conspicuous trend in the studies within this group is the analogous result of an insignificant effect of African RTAs on bilateral trade or very large estimates.

Common to the above three groups of studies is the omission of the MRT or the use of the remoteness index – GDP weighted average distance. This is not consistent with the theoretical derivation of the gravity model. The omission of the MRT also contributes to an upward bias for the estimates of standard variables in the gravity model (Anderson and van Wincoop, 2003).

Considering the fact that results from these previous studies exhibit extensive variations, I conduct a meta-analysis to determine a combined effect size that accounts for publication bias. To explain the potential heterogeneity in these contrasting studies, I also employ a multivariate meta-regression analysis (MRA), following the steps of Stanley and Doucouliagos (2012). The meta-analysis is an appropriate tool as these previous studies adopted the same model specification, the gravity equation.

In the next section, I discuss the data used for the meta-analysis, as well the sources for the data used for the gravity model estimation.

3. Data description

In meeting the objectives of the study, I use two sources of data. First, the data for the meta-analysis, in which I collate data on effect size (ES), econometric methods and characteristics of previous empirical studies. The ES (δ) is the reported point estimate or coefficient of the RTA's impact on bilateral trade. The effect sizes are all comparable as they were all obtained from the previous studies that used the gravity model. In addition, they all use an indicator variable to measure RTA. Apart from these, other studies that use non-linear estimations also report the marginal effects, hence all the estimates are comparable. Essentially, the collated ESs are treated as individual observations; used to test the hypothesis that the combined ES is statistically and significantly different from zero. In order to stay clear of selection bias, I choose almost all the available papers focusing on African RTAs provided the estimates and their standard errors are available. The search produces a limited number of studies that specifically look at African RTAs, and a fair number of them do not provide relevant details for a robust meta-analysis.[2] In all, 139 estimates from 14 individual studies were collated. These studies are the most cited papers as far as

[2] The search for empirical studies for the meta-analysis was last updated on 15th December 2015. I rely extensively on Google Scholar to search for empirical papers on African RTAs, using the keywords *RTA, trade, Africa and gravity* and then augment the list using a snowballing technique by looking at the references of the studies in case the search engine did not find them all.

African RTAs are concerned. A descriptive analysis on the studies used for the meta-analysis is provided in Table A2 in the Appendix 1.

To achieve the second core objective of this study – comparing the different estimation methods and also assessing the comparative performance of the five major RTAs in Africa – I use data on the bilateral exports of 47 African countries.[3] Descriptive statistics on the main gravity variables are reported in Table A3 in Appendix 1. I restrict the estimation methods to all the methods used in the previous studies and compare them with the PPML estimation. The time period is restricted to 1980-2006, as the sample studies considered in the meta-analysis have their trade flows measured within this same period. The data on export flow was obtained from the IMF Direction of Trade Statistics and the standard gravity model variables from the *Centre d'Etudes Prospectives et d'Informations Internationales* (CEPII). The main variables used for the gravity model are defined in Section 4.3.

4. Empirical Strategy and Results

4.1. Meta-Analysis

A meta-analysis involves collecting empirical results from individual studies with the purpose of summarizing, integrating and examining the combined effects of the contrasting studies (Wolf, 1986). The combination of different studies helps to derive more precision and investigates the discrepancies in those studies. Stanley (2001) concurs that combining the results taken from individual studies would give more insight and greater explanatory power. Some of its contemporary application can be seen in studies such as Rose and Stanley (2005), Cipollina and Salvatici (2010), Genc *et al*. (2011) and Head and Mayer (2014).

In the literature, conducting a meta-analysis (regression) might help to achieve the following two main objectives. First, to derive a single effect size from many combined individual studies and to test whether there is a genuine empirical effect (Stanley, 2001). The second objective may be realized through a moderator analysis or MRA to identify objectively how the characteristics of the study influence or explain the variation in results. The MRA explains the research process itself and links the sensitivity of the reported estimates to the researchers' choice of data, estimation methods

[3] These RTAs are perceived as the main building block for continental integration (Teshome, 1998). The RTAs include the Economic Community of West African States (ECOWAS) in Western Africa, Southern African Development Community (SADC) in Southern Africa, the Arab Maghreb Union (AMU) in Northern Africa, the Economic Community of Central African States (ECCAS) in Central Africa and the Common Market for Eastern and Southern Africa (COMESA) in Eastern and Southern Africa. These RTAs span and represent all the regions on the continent.

and econometric models (Stanley, 2005).

The estimates from these studies show varied heterogeneity in terms of sign, size and significance. The descriptive statistics for the estimates indicate a mean (0.86) and a median (0.76); however, the minimum and maximum estimates are -2.61 and 3.73, respectively, thus indicating the presence of outliers. With regard to the size of the estimates, I have divided them into four different categories. The details are provided in Table 1. Over 40% of the estimates exhibit a large size of RTA effects on trade, with 74% of these estimates also statistically significant.

[Table 1]

In Table 2, I examine whether the estimates differ in the case of different estimation methods; the results indicate that the mean estimates are greater than 1 in the OLS, RE and Tobit estimations, an indication of obvious upward bias. This reflects the inadequacies of these techniques in addressing the econometric concerns with the gravity model. The Tobit estimation also has the lowest number of estimates that are statistically significant.

[Table 2]

To estimate the combined ES, two approaches are espoused according to Card (2012); the fixed effect method (FEM) and the random effect method (REM). These methods are used to address the issues of within- and between-study heterogeneity because pooling data from different studies would exhibit some degree of heterogeneity. Hence, a simple measure that gives an equal weight to each estimate may be misleading. In evaluating heterogeneity, I conduct the Hedge *Q* test. This tests whether the deviation in the ESs of the studies exceeds the amount of expectable deviation due to sampling fluctuation. However, the *Q*-statistic is limited in determining whether the extent of heterogeneity or the percentage of variability in the ESs is due to heterogeneity or sampling fluctuation. To determine the magnitude of heterogeneity, I use the *I*-square (I^2) index. This index indicates the proportion of variability between studies compared to the total variability among effect sizes (Higgins and Thompson, 2002).[4] Details on the meta-analysis on overall RTA effects are reported in Table 3.

[Table 3]

[4] See Appendix 2 for the computation of Q-statistc and I-Square index

The results consist of the test of heterogeneity and this rejects the null hypothesis of homogeneity. Also, included in the results is the *Z*-test, which tests the significance of the combined ES. The *Z*-test indicates that the combined ES under both FEM and REM are significant. For the test of heterogeneity, Cipollina and Salvatici (2010) indicate that the test could be spurious, in that homogeneity may be rejected even when the individual ESs do not differ significantly. This is attributed to the low statistical power of the *Q* test. However, Card (2012) provides a simple chart using the I^2 index as the rule of thumb to make inferences about heterogeneity. The chart displays the minimum detectable heterogeneity in connection with the number of studies that will result in a statistically significant value of *Q*. If the minimum detectable heterogeneity is less than the computed I^2 index in a specific number of studies, then concluding heterogeneity is reasonable. Based on this, the conclusion of heterogeneity is adequate.

For the combined ES of RTAs, the confidence interval (CI) under both FEM and REM is greater than zero. This is a possible indication that African RTAs may have a positive trade effect. The estimates, obtained under FEM (0.406) and REM (0.634), are relatively smaller compared to the simple mean effect of 0.86. The results indicate that the African RTAs increase bilateral trade between 49 and 89%. The I^2 index indicates that about 94% of total variance is explained by between-study variance.

[Table 4]

Table 4 displays the meta-analysis of the RTA effect under different estimation methods. With regard to the ES for the different estimation techniques, the RE and OLS estimates report the highest RTA effects of 140 to 250%. The FE, HT and WLS estimates fall within the confidence interval of the random effect estimates of the overall RTA.

Inference from results based on weighted and un-weighted averages must be drawn with caution, especially if there is an evidence of publication bias (Stanley and Doucouliagos, 2012). Thus, the next section conducts a publication bias test and a MRA (to determine how different characteristics of studies affect the estimates).

4.2. Publication Bias and Meta-Regression

Although the previous studies employed the same gravity specification, there are some differences especially in the estimation techniques, type of data (cross-sectional or panel data), the different RTAs under study, the way econometric concerns of the zero flows and MRT were dealt with and whether the studies have been published or not. One major criticism of meta-analysis is publication bias, which can affect the combined ES. This mostly happens because of the preference of academic journals to accept papers that report statistically significant results. A conventional method common in meta-analysis to determine this publication bias is the funnel plot. Typically, the funnel plot is is a scatterplot of the inverse of the standard errors (1/Se) relative to the individual effect sizes. Figure 1 is the funnel plot of the individual estimates.

[Figure 1]

The funnel plot indicates the absence of publication bias if the plot has a pictorial view of an inverted funnel. The funnel plot typically has the shape of an inverted funnel but it does not have a perfectly symmetric shape. Rose and Stanley (2005) note that asymmetry is a mark of publication bias. Thus, I use a simpler statistical testing technique— the funnel asymmetry test (FAT). This test confirms the presence or absence of publication bias. This involves regressing ESs on their standard errors as in (1)

$$\delta_i = \beta_1 + \beta_0 Se_i + \varepsilon_i \qquad (1)$$

Stanley (2005) finds that since the ESs are obtained from individual studies with different sample sizes and modelling variation, the disturbance term will be heteroscedastic. Thus, the WLS is an apparent method to obtain the efficient coefficient, resulting in the transformation of equation (1) by dividing by Se_i.

$$t_i = \beta_0 + \frac{1}{Se_i}\beta_1 + \epsilon_i \qquad (2)$$

In equation (2), I regress the t-statistic on the inverse of the standard errors and test for a statistical significance of $\beta_0 = 0$, which is FAT. The FAT is considered the test of asymmetry of a funnel plot and it tests the presence of publication bias. This is because without publication bias the ESs will be independent of the standard errors. In addition, from equation (4), I conduct the precision-effect test (PET), which is a test of the statistical significance of $\beta_1 = 0$. The result indicates a true effect. A more robust approach indicated by Stanley and Doucouliagos (2012) to obtain an improved meta-average after correction of publication bias is the precision-effect estimate with standard error (PEESE). PEESE uses the variance rather than standard error as shown in equation (3).

$$\delta_i = \beta_1 + \beta_0 {Se_i}^2 + \varepsilon_i \quad (3)$$

[Table 5]

Table 5 reports the results for both FAT-PET in the odd columns and PEESE in the even columns. Because of possible dependence in the reported estimates, I cluster the standard errors by the authors of the studies and the results are reported in columns (1) and (2). However, clustering also poses an additional statistical problem due to the insufficient number of clusters in the sample (Cameron *et al*. 2008). Thus, I conduct a robustness test by using wild bootstrap as recommended by Cameron *et al*. (2008) in colums (3) and (4). The two approaches indicate statistically significant β_0, thus revealing an asymmetry or publication bias, which could not be viewed explicitly in the funnel plot. The PET confirms a genuine RTA effect as the precision variable was statistically significant. The meta-average corrected for publication bias has an estimate of 0.240 while the PEESE has a slightly higher effect of 0.282. This indicates a general RTA effect of 27% ($e^{0.240}$-1) to 32% ($e^{0.282}$-1). This implies that that export flow is 27-32% higher for African countries that share membership in the same regional bloc compared to countries that do not. This confirms publication bias ranging between 2 to 4 if compared with the weighted and un-weighted averages in previous empirical papers on African RTAs.

[Table 6]

Another major concern is the inadequate size of the sample of previous studies. Thus, one may be concerned that our results may be sensitive to the specific studies included in the sample. To test for the influence of single studies, I conduct a Jack-knife experiment, where the FAT-PET-PEESE regressions are run afresh excluding one study at a time. The results are reported in Table 6 and they do not deviate from the estimates in Table 5. Not only are the coefficients of the regression similar but their significance are also comparably stable. This indicates that no individual studies largely influence the results.

I employed a multivariate MRA in order to assess how the study characteristics and estimation techniques influence findings from individual studies. In this MRA, the t-statistics of the effect sizes are regressed on the study characteristics and different estimation techniques. All these covariates have been divided by standard error in line with Stanley *et al*. (2013). Results of the MRA are presented in Table 7. Two models are estimated as represented by the two columns. Column (1) includes all the moderator variables in exception of the dummies of the specific RTAs. Column (2) includes all the moderator variables as well as the RTAs dummies. In both models, the intercept remains insignificant. Stanley and Doucouliagos (2012) state that neither publication bias nor true effect is represented by any single MRA coefficient. They recommend a joint F-test for the variables to determine publication bias. Thus, I conduct a joint F test for each model and they are all highly significant.

[Table 7]

The MRA results indicate that the study characteristics affect the RTA effects on trade considerably and the estimation techniques significantly influence the estimates. Additionally, how the econometric concerns of zero flows and MTR are accounted for, do influence the estimates. Studies that control for MRT, using the remoteness index, tend to have lower estimates and similarly apply to studies that control for zero flows, by using the Tobit estimator or replacing zero flows with an arbitrary value. This emphasizes that the trade-creating effect of RTAs may also be significantly overstated if the two main econometric concerns are disregarded.

In the next sections, I estimate the RTA effects and compare the estimation methods employed in previous studies with the application of more theoretically-consistent MRT and PPML.

4.3. The Gravity Model

The gravity model specifies that trade flow is directly proportional to the exporter's gross domestic product (GDP) (Y_i) and the importer's GDP (Y_j), and inversely proportional to the distance (d_{ij}) between countries i and j. The GDP of country i signifies the capacities of the exporter as supplier to all destinations j and similarly, the GDP of country j indicates the market demand potential of the importer from all origins i.

The specification of the model has evolved over the years, evolving from the naive specification, in which the traditional gravity equation is augmented with bilateral accessibility variables only. Anderson and van Wincoop (2003) emphasize that trade flow would not depend only on bilateral accessibility between two trading countries but their relative position to the rest of world (the so-called multilateral resistance term). This term is unobserved, hence may lead to omitted variable bias.

Apart from this omitted variable bias, there is the concern of possible endogeneity emanating from reverse causality or simultaneity. The simultaneity arises when countries that trade extensively are more likely to form trade agreements. In an African context, this may not be serious as most of these African RTAs were formed when intra-regional trade flows were low. However, the main variable of interest, RTA, is also lagged, which can also correct for simultaneity (Baier *et al*., 2008). Endogeneity may also arise from the omitted variables, such as historical, cultural and political factors that can affect the bilateral trade between two countries. This may produce inconsistent estimates when relevant proxies for these factors are not used to control for them. Essentially, the fixed effects and time-varying political and economic variables would deal with the omitted variables in the gravity equation. Thus, the baseline model is specified in the log-log functional form (equation 4), with both the dyadic fixed effects and time effects. The estimation of the gravity model strictly measures the ex-post effect of African RTAs and follows several other papers to use an indicator variable to capture an RTA effect (Baier *et al*., 2008; Egger *et al*., 2011; Kohl, 2014). Since the African RTAs are regional economic blocs, the effect captures broadly market integration, regional co-operation and development integration.

$$\ln\left(\mathrm{X_{ijt}}\right) = \alpha_{\mathrm{ij}} + \alpha_{\mathrm{t}} + \beta\ln\mathrm{M_{it}} + \gamma\ln\mathrm{M_{jt}} + \rho\mathrm{D_{ij(t)}} + \delta\mathrm{RTA}_{ijt} + \varepsilon_{\mathrm{ijt}} \quad (4)$$

α_{ij} is the dyadic fixed effect, α_t are the time dummies and ε_{ijt} is the error term. $M_{i(j)t}$ is the vector of monadic variables of the exporter (importer) in the gravity equation, and they consist of GDP, MRT, population, geographical area, democracy and conflict indicators. $D_{ij(t)}$ is the vector of dyadic time-invariant (variant) variables; consisting of distance between i and j, indicator variables that equal one if i and j share a border, have a common language, have a common currency and are both members of WTO/GATT. Included in the set of controlling variables are political and conflict indicators that can affect trade flows in line with Aidt and Gassebner (2010). These include a democracy indicator from Cheibub *et al.* (2010), which indicates whether a country is democratic or autocratic, and a conflict indicator (the number of attempted and successful coup d'etats sourced from Marshal *et al.* (2014).

The variables of interest include a dummy for all the five major RTAs, AMU, COMESA, ECCAS, ECOWAS and SADC. The control group is the pair of African countries that do not share membership of regional economic blocs. According to Baier *et al.* (2008), the RTAs signed in a particular year could not have effect contemporaneously; the effect takes 5 to 10 years. Thus, there is a need to lag the RTAs to cater for the phasing in that characterized most RTAs. The dependent variable (X_{ijt}) is the export from country i to country j at time t and independent variables of interest are the lag RTAs for five years.

4.4. Econometric Concerns

Introducing dyadic fixed effects cannot proxy for the MRT because they are not time-varying. However, the time-varying fixed effects in panel data lead to a number of problems (Baier and Bergstrand, 2010). For instance, they cite that many important policy relevant variables are differenced away. In order to address this issue, I explicitly introduced the Baier and Bergstrand (2010) proxy variable for measurement of MRT, which is consistent with theoretical derivation of the gravity model. This approach has been used in Egger and Nelson (2011) and Berger *et al.* (2013). In this approach the multilateral resistance term is derived from the first-order, log-linear Taylor expansion of the multilateral price equations within the theoretical gravity equation, which yields an empirical reduced-form equation (5). This measure is a simple average of multilateral relative to world trade cost, and this is replaced with observable dyadic trade variables such as distance, border, common currency, language, etc.

$$MRT_{i(j)t} = \frac{1}{N}\left[\sum_i^N lnt_{ijt} + \sum_j^N lnt_{ijt} - \frac{1}{N}\left(\sum_i^N \sum_j^N lnt_{ijt}\right)\right] \quad (5)$$

For the zero flows, different solutions have traditionally been used. Apart from the majority of previous empirical studies dropping the zero values, others rely on the Tobit estimation and the adding of arbitrary small value to trade flow. These approaches would lead to inconsistent estimates, especially if the zero flows are not randomly distributed. This seems to be the case in this sample, as about 85% of the zero flows occur in country-pairs that are not involved in any RTA. The inconsistency of the estimates will be pervasive in an all-African trade flow data, as SST (2006) indicate that the severity of the inconsistency depends on the proportion of zero flows. In dealing with the zero flows, two major approaches are known as well-behaved, the Heckman-based method proposed by Helpman *et al.* (2008) and the PPML proposed by SST (2006). However, Head and Mayer (2014) show with simulations that the PPML is the best approach in handling the zero flows. From that point of view, I rely on the PPML as a solution to deal with the zero flows. For the PPML, the expected trade is modelled using an exponential function as in equation (6), where exports are now measured at level (rather than using the logarithmic function).

$$E(X_{ijt}|Z_{ijt}) = \exp(\alpha_{ij} + \alpha_{t} + \beta \ln M_{it} + \gamma \ln M_{jt} + \gamma D_{ij(t)} + \delta RTA_{ijt} + \varepsilon_{ijt}) \quad (6)$$

In assessing the sensitivity of the RTA effects on trade, I employ different estimation methods used by previous studies in dealing with zero flows. Using different estimation methods helps to compare the estimation methods of previous studies with the PPML and also to empirically determine the sensitivity of the RTA effects on trade to the different estimation methods. Details on the effects of RTAs are reported in Table 8 and coefficients of control variables in Table 8A in the Appendix 1.

[Table 8]

The standard controlling variables in models have expected signs. PPML estimates for exporter and importer GDPs are not close to one, a point well-noted by SST (2006). Focusing on trade policy variables of interest, the RTAs, one noticeable trend is the sensitivity of the impact of RTAs to the different estimation methods. The estimates differ considerably in sign, size and significance. Comparing the other estimation techniques to PPML in columns 6 and 7 there is an obvious observation of upward bias in the coefficient of the RTAs. In column 7, I control for multilateral resistance using Baier and Bergstrand (2010) proxy, and the magnitude of the estimates reduces significantly.

With the exception of PPML, the coefficients of the other estimation techniques report a very high magnitude of RTA effects on bilateral trade. For instance, the approach of adding an arbitrary value (1) to exports reports an RTA impact of over 900% ($e^{2.542} - 1$) in contrast to the range of 90% to 200%, when zero flows and multilateral resistance are correctly dealt. A 900% impact is obviously an overestimated effect and unrealistic. This upward bias is conspicuously higher in the Tobit and FE estimations, when zero flows are replaced with small values. Although the impact of regional economic blocs on trade in the PPML model is still large, this is significantly lower than estimates obtained from other estimation methods and the combined effect size from the meta-analysis. The magnitude of the effect could be large, especially if the impact captures market integration as well as regional co-operation and development integration. The results are comparable to a more current study by Kohl (2014), who finds an estimate of 1.156 (217%) for SADC, after controlling for some major econometric concerns.

Apart from the significantly overestimated impact of these regional blocs in other estimation methods, most of the blocs tend to have significant positive effects as well, which may be a spurious outcome. A comparative assessment of the regional economic blocs delineates a varying effect, an indication that the performance and progress of the RTAs across the continent are unequal. Specifically, ECOWAS and SADC are the only regional blocs that have significant positive impact on trade, while COMESA have a positive effect but not statistically significant. AMU and ECCAS have negative effects but these are not significant. These two blocs are almost defunct because most of the member states are highly politically unstable and ravaged by a series of conflicts. The positive impact of ECOWAS and SADC compared to the other regional blocs is also plausible. ECOWAS and SADC are more advanced, especially in promoting regional co-operation. For instance, both blocs have implemented successfully the free movement of people across the member states and there is also sectoral coordination of the economic and physical infrastructure within both blocs. Examples of regional projects include the West Africa Gas Pipeline, which supplies gas from Nigeria to other members of ECOWAS and an energy power pool within SADC.

5. Conclusion

In summary, this paper revisits the issue of the impact of African regional blocs on trade using two different methods. The first method uses meta-analysis and meta-regression to review the results of previous empirical papers that assessed the impact of various African RTAs on trade using meta-analysis. The results from the meta-analysis of previous empirical papers indicate that there was an explicit upward bias in effect of RTAs on trade arising from publication bias. The meta-regression indicates that African RTAs have general positive effects on bilateral trade, with an impact of about ranging 27-32%. Augmenting the meta-regression with the moderator variables also indicates that the size of the effect of these previous papers critically depends on the characteristics of the study and the estimation techniques employed.

The second method uses the gravity model to assess the trade-creating impact of five main regional blocs on the continent. The results from the gravity models support the meta-analysis by demonstrating that the effect of the RTAs tends to be overestimated when MRT and zero flows are incorrectly dealt with. In addition, from the gravity model estimations, the results indicate that contrary to the general pessimistic connotation of all African RTAs as not contributing significantly to intra-African trade, ECOWAS and SADC blocs were found to have contributed significantly to trade. Thus, the pace of progress and performance across African RTAs is highly unequal. The result gives credence to the UNECA (2012) report that African RTAs have shown contrasting outcomes, with some achieving tangible and modest outcomes whereas others have had disappointing results.

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Figure 1: Funnel plot

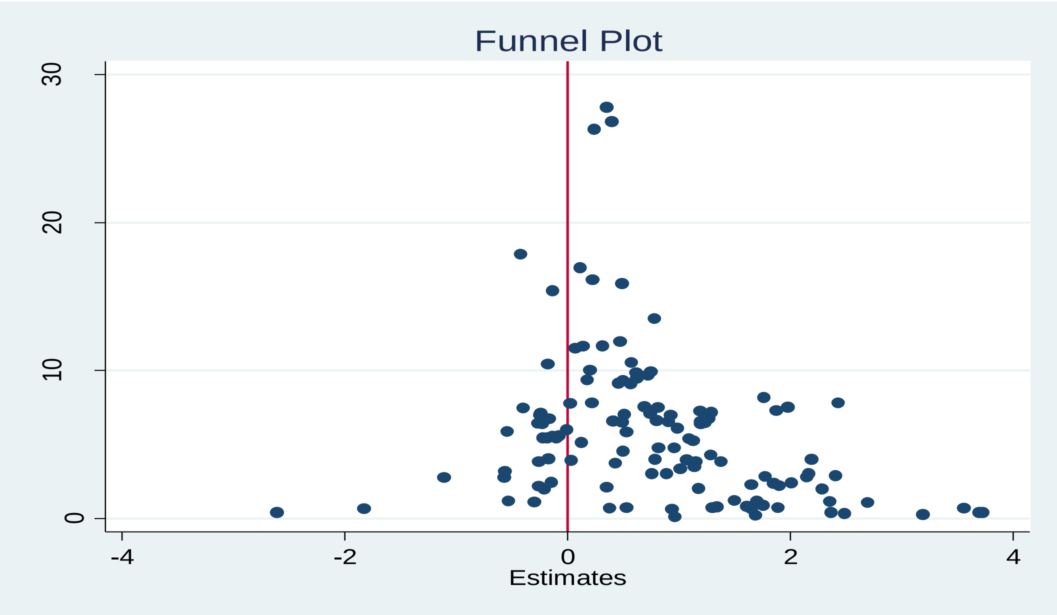

Table 1: Categorization of the effect sizes

Ranges of RTA Effect on Trade (estimates)	Frequency	Percentage
estimates≤-1	5	3.6
-1<estimates<0	26	22.30
0<estimates<1	50	35.97
estimates≥1	58	41.73
Total	139	100

Table 2: Estimates under different estimation techniques

Methods	Frequency	Significant estimates	Mean	Std. Dev.	Min.	Max.
Fixed Effect (FE)	16	75%	0.54	0.86	-0.57	2.43
Hausman-Taylor (HT)	12	92%	0.76	0.86	-0.54	2.41
Non-Linear Squares (NLS)	4	100%	0.44	2.01	-1.40	2.57
Ordinary Least Sqaures (OLS)	30	87%	1.04	0.78	-0.40	2.49
Random Effect (RE)	3	100%	1.30	1.03	0.12	2.01
Tobit (TE)	50	60%	1.05	1.35	-2.61	3.73
Weighted Least Sqaures (WLS)	24	71%	0.52	0.56	-0.26	1.29

Table 3: Meta-analyses of RTA effects on trade

Effects	Pooled estimates	Lower bound	Upper bound	Q-Statistic	I-square	Z-Statistic
Fixed	0.406	0.383	0.429	1981.24	93.8%	34.98
Random	0.634	0.526	0.742	1981.24	93.8%	34.98

Table 4: Meta-analysis of estimated RTA effects under different estimation methods

Methods	Pooled estimates	ES	Lower bound of 95% CI	Upper bound of 95% CI	Q-Stat	I-square	Z-Stat
RE	FEM	0.196	0.083	0.309	41.040	95.10%	3.4
	REM	1.262	-0.151	2.675	41.040	95.10%	3.4
OLS	FEM	0.600	0.542	0.658	477.470	93.90%	20.3
	REM	0.896	0.635	1.158	477.470	93.90%	20.3
FE	FEM	0.270	0.232	0.307	703.510	97.90%	14.2
	REM	0.532	0.249	0.815	703.510	97.90%	14.2
HT	FEM	0.412	0.343	0.481	177.900	93.80%	11.7
	REM	0.651	0.334	0.968	177.900	93.80%	11.7
Tobit	FEM	0.395	0.334	0.457	136.450	72.90%	12.6
	REM	0.451	0.216	0.686	136.450	72.90%	12.6
WLS	FEM	0.567	0.515	0.620	300.650	92.30%	21.2
	REM	0.525	0.333	0.717	300.650	92.30%	21.2

Table 5: Meta-regression analysis (FAT-PET-PEESE)

	(1)	(2)	(3)	(4)
	Cluster adjusted		Wild bootstrapped	
VARIABLES	FAT/PET	PEESE	FAT/PET	PEESE
Precision ($\mathbf{1}/_{\boldsymbol{se}}$)	0.240***		0.240***	
	(0.0768)		(0.01)	
Inverse of precision square ($\mathbf{1}/_{\boldsymbol{se^2}}$)		0.282***		0.282***
		(0.0418)		(0)
Constant ($\boldsymbol{\beta_0}$)	1.721**	7.476	1.721***	7.476*
	(0.656)	(4.308)	(0.02)	(0.056)
Observations	123	123	123	123
R-squared	0.094	0.471	0.094	0.471

Note: Columns (1) and (2) used robust standard errors clustered by the authors (standard errors in parentheses). Columns (3) and (4) used wild bootstrap (p-value in parentheses). *** (**) [*] denote significance at p<.01 (p<.05) [p<.10]. Subramanian (2003) and Kirkpatrick and Watanabe (2005) studies were not included in the meta-regression because they had estimates without their standard errors or t-statistics.

Table 6: Jack-knife Experiment for the FAT-PET-PEESE

Dropped individual studies	PET coefficient	PEESE coefficient	FAT coefficient	Dropped observations	Total observations
Afesorgbor and van Bergeijk (2011)	0.224***	0.283***	1.297**	8	115
	(0.065)	(0.040)	(0.497)		
Carrere (2004)	0.245**	0.283***	1.684**	5	118
	(0.078)	(0.042)	(0.683)		
Cernat (2001)	0.257**	0.284***	1.412**	12	111
	(0.073)	(0.042)	(0.626)		
Deme (1995)	0.237**	0.282***	1.691**	4	119
	(0.076)	(0.042)	(0.666)		
Elbadawi (1997)	0.221**	0.279***	1.977**	12	111
	(0.078)	(0.042)	(0.775)		
Foroutan and Pritchett (1993)	0.212**	0.243***	1.917**	6	117
	(0.080)	(0.024)	(0.707)		
Herman et al. (2011)	0.243**	0.282***	1.693**	1	122
	(0.077)	(0.042)	(0.663)		
Loggo and Sekkat (2004)	0.228**	0.280***	1.858**	10	113
	(0.079)	(0.042)	(0.791)		
Musila (2005)	0.222**	0.278***	1.926**	42	81
	(0.090)	(0.042)	(0.857)		
Ogunkola (2001)	0.223**	0.281***	1.917**	6	117
	(0.076)	(0.042)	(0.721)		
Ott and Patino (2009)	0.278***	0.301***	1.600**	2	121
	(0.088)	(0.046)	(0.630)		
Tuckson (2012)	0.341**	0.342***	1.549**	15	108
	(0.115)	(0.074)	(0.675)		

Note: Robust standard errors clustered by authors in parentheses. *** (**) [*] denote significance at p<.01 (p<.05) [p<.10]. Subramanian (2003) and Kirkpatrick and Watanabe (2005) studies are not included because they have missing standard errors or t-statistics.

Table 7: Meta-regression analysis results

Dependent variable: t-statistics	(1)	(2)
Inverse of the standard error	1.932***	1.877***
	(0.476)	(0.428)
Control for Zero flows	-0.353**	-0.432**
	(0.142)	(0.171)
Published	-1.078*	-0.456
	(0.500)	(0.447)
Control for MRT	-1.054*	-0.821**
	(0.506)	(0.364)
Tobit	-0.315**	-0.364***
	(0.109)	(0.0685)
Number of countries	0.00241	-0.00310
	(0.00226)	(0.00296)
Type of data (Cross section=0/panel=1)	0.0940	0.141
	(0.204)	(0.332)
Fixed effect	-0.638	-0.142
	(0.367)	(0.123)
Hausman-Taylor	-0.798**	-0.408*
	(0.320)	(0.223)
Ordinary least square	-0.261***	-0.232***
	(0.0377)	(0.0351)
Random effect	-0.894***	0.0755
	(0.199)	(0.127)
Constant	0.140	0.679
	(0.513)	(0.513)
Observations	123	123
R-squared	0.393	0.765
F	10429***	60.30**
RTA included	No	Yes

Note: Robust standard errors clustered by authors in parentheses. *** (**) [*] denote significance at p<.01 (p<.05) [p<.10]. All the moderator variables have been transformed by dividing them with their standard errors. For estimation methods, the WLS is used as reference category. The NLS is not included in the regression because of missing observations. In columns (2), the degree of freedom will be reduced by 10 (number of RTAs dummies), however, the estimates are comparable to the estimates in column (1). Thus, indicating the inclusion of more covariates does not affect the results significantly.

Table 8: Empirical results under different estimation methods

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Estimator	OLS	RE	FE	FE	Tobit	PPML	PPML
Dep. variable	lnX_ij	lnX_ij	lnX_ij	Ln(X_ij+1)	Ln(X_ij+1)	X_ij	X_ij
African RTAs							
AMU	1.051***	0.233	0.165	-0.0358	-1.076*	0.0173	0.00241
	(0.133)	(0.272)	(0.296)	(0.610)	(0.636)	(1.532)	(0.197)
COMESA	0.884***	0.881***	1.409***	1.411***	2.656***	0.452*	0.390*
	(0.113)	(0.283)	(0.359)	(0.457)	(0.612)	(0.251)	(0.234)
ECCAS	-0.491***	-0.324	-0.504	-0.267	0.155	1.470**	-0.0238
	(0.138)	(0.344)	(0.465)	(0.771)	(0.803)	(0.661)	(0.378)
ECOWAS	0.871***	0.376**	-0.303	0.258	5.664***	1.765***	1.097***
	(0.0682)	(0.166)	(0.235)	(0.669)	(0.528)	(0.478)	(0.361)
SADC	1.434***	0.756***	0.536	2.542***	3.678***	1.141	0.649**
	(0.105)	(0.267)	(0.332)	(0.836)	(0.644)	(0.831)	(0.320)
Observations	17,709	17,709	17,709	34,845	34,845	34,511	34,511
Fixed effects	No	Yes	Yes	Yes	Yes	Yes	Yes
Correct for Zeros	No	No	No	No	Yes	Yes	Yes
MRT	No	No	No	No	No	No	Yes

Note: For the Tobit and PPML, the reported coefficients are the average treatment effects, thus comparable to other models. All the controlling standard gravity variables and B&B multilateral resistance terms for trade cost variables are reported in Table 8A in the Appendix. The RTA variables are lagged by a 5 year period and qualitatively the results do not change for lag periods less than 5 years. Time fixed effects are included. Cluster robust standard errors by country-pairs in parentheses. *** (**) [*] denote significance at p<.01 (p<.05) [p<.10].

Appendix 1:

Table 8A: Empirical results under different estimation methods

	(1)	(2)	(3)	(4)	(5)	(8)	(9)
Estimator	OLS	RE	FE	FE	Tobit	PPML	PPML
Dep. variable	lnX_ij	lnX_ij	lnX_ij	Ln(X_ij+1)	Ln(X_ij+1)	X_ij	X_ij
Ln GDP_i	1.184***	0.873***	0.631***	0.454***	1.273***	0.655***	0.668***
	(0.0239)	(0.0657)	(0.105)	(0.154)	(0.128)	(0.152)	(0.112)
Ln GDP_j	0.883***	0.520***	0.288***	0.540***	1.351***	0.454***	0.526***
	(0.0220)	(0.0529)	(0.0875)	(0.158)	(0.123)	(0.106)	(0.0982)
Ln population_i	-0.0760**	0.173**	-0.739	0.371	1.339***	0.339*	0.371**
	(0.0325)	(0.0867)	(0.625)	(0.973)	(0.194)	(0.186)	(0.155)
Ln population_j	-0.135***	0.207***	2.205***	2.017**	0.860***	0.296**	0.200
	(0.0291)	(0.0764)	(0.623)	(0.950)	(0.190)	(0.138)	(0.122)
Ln area_i	-0.223***	-0.195***					
	(0.0197)	(0.0516)					
Ln area_j	-0.218***	-0.177***					
	(0.0190)	(0.0502)					
Democracy_i	-0.0351	0.0801	0.136	-0.270*	-0.647***	0.112	0.153
	(0.0493)	(0.0861)	(0.0929)	(0.146)	(0.154)	(0.157)	(0.152)
Democracy_j	0.00533	0.265***	0.301***	0.202	0.427***	-0.0586	-0.0233
	(0.0504)	(0.0823)	(0.0877)	(0.138)	(0.154)	(0.136)	(0.148)
Conflict_i	0.169***	0.0760*	0.0810*	0.223***	0.292**	-0.0467	-0.0444
	(0.0621)	(0.0445)	(0.0449)	(0.0696)	(0.139)	(0.0688)	(0.0572)
Conflict_j	0.00386	0.00663	0.0237	0.172**	0.301**	-0.0623	-0.0583*
	(0.0604)	(0.0442)	(0.0447)	(0.0693)	(0.135)	(0.0513)	(0.0354)
Common currency	0.281***	0.0190	-0.717*	-0.371	3.134***	0.904**	1.751***
	(0.0699)	(0.206)	(0.376)	(0.344)	(0.535)	(0.360)	(0.617)
WTO/GATT	0.415***	-0.0599	-0.297**	-0.384*	-0.130	0.133	0.636***
	(0.0480)	(0.110)	(0.140)	(0.228)	(0.195)	(0.162)	(0.205)
Ln distance_ij	-1.363***	-1.300***					
	(0.0389)	(0.111)					
Common language	0.319***	0.397**					
	(0.0568)	(0.158)					
Border	0.947***	1.475***					
	(0.0681)	(0.226)					
Common colonizer	0.562***	0.490***					
	(0.0573)	(0.166)					
MRT_RTA							-0.00172
							(0.169)
MRT_WTO							-0.481
							(0.405)
MRT_distance							-1.600***
							(0.143)
MRT_border							0.354
							(1.177)
MRT_language							1.031***
							(0.245)
MRT_currency							-1.946**
							(0.873)
Constant	9.715***	13.18***	1.392	-6.040*	-24.51***	2.928*	1.313
	(0.477)	(1.271)	(2.339)	(3.288)	(1.430)	(1.762)	(1.536)
Observations	17,709	17,709	17,709	34,845	34,845	34,511	34,511
R-squared	0.378	-	0.094	0.109	-	-	-

Notes: Table 8A is a continuation of Table 8, reporting the coefficients for standard gravity and political variables. Cluster robust standard errors in parentheses. *** (**) [*] denote significance at p<.01 (p<.05) [p<.10].

Table A1: Regional blocs in Africa and current status

RTAs (year)	Members	Main Objectives	Current Status
SADC (1994)	Angola, Botswana, DR Congo, Lesotho, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia, Zimbabwe,	-To promote deeper economic integration. - -To establish common political, economic and social policies and values. -To strengthen regional security.	-Tariffs removed and cover all products. -Power pool in place -Peace and security mechanism in place -Macroeconomic convergence in place -Free movement of people
ECOWAS (1975)	Ghana, The Gambia, Sierra Leone, Nigeria, Guinea, Togo, Benin, Cote D'Ivorie, Senegal, Mali, Liberia, Cape Verde, Burkina Faso, Niger, Guinea Bissau	-To promote cooperation and development in all economic activities. -To establish an FTA -To establish a common external tariff -Ensure free movement of people.	-Tariffs removed on unprocessed goods and traditional handicrafts. -Full elimination on tariffs on industrial good started by Benin -Second monetary zone in progress - Free movement of people -Macroeconomic convergence in place
COMESA (1993)	Burundi, Comoros, Libya, Djibouti, DR Congo, Egypt, Eritrea, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Rwanda, Seychelles, Sudan, Swaziland, Uganda, Zambia, Zimbabwe.	-To Promote development, regional cooperation and integration. -To establish full FTA -To create a custom union.	-FTA established and covers all goods -A custom union launched in 2009
AMU (1989)	Algeria, Libya, Morocco, Mauritania, Tunisia	-To establish a common market. –To provide intra-union free trade, -To erect a common external tariff -Ensure free movement of people	-FTA established and covers agricultural products -High political instability and insecurity hindering progress
ECCAS (1983)	Angola, Burundi, Chad, Cameroon, Central African Republic, DR Congo, Congo, Equatorial Guinea, Gabon, Rwanda, Sao Tome and Principe	-To promote regional cooperation and integration. -To abolish trade restrictions -To establish a common external tariff.	-FTA established. -insecurity in the region has hindered progress

Compiled from: Söderbaum (1996) and UNECA (2012).

Table A2: Descriptive results from the studies

Authors	Mean	SD	Median	N	Min	Max
Afesorgbor and van Bergeijk (2011)	2.013	0.267	1.927	8	1.764	2.434
Carrere (2004)	0.848	0.496	1.140	5	0.200	1.290
Cernat (2001)	1.282	0.601	1.070	12	0.500	2.190
Deme (1995)	0.678	0.240	0.655	4	0.410	0.990
Elbadawi (1997)	1.097	2.109	0.845	12	-2.610	3.730
Foroutan and Pritchett (1993)	0.748	1.418	0.130	6	-0.530	2.700
Herman et al. (2011)	1.903	0.000	1.903	1	1.903	1.903
Kirkpatrick and Watanabe (2005)	1.528	0.802	1.605	12	-0.190	2.430
Loggo and Sekkat (2004)	1.807	0.626	1.675	10	0.940	3.190
Musila (2005)	0.422	0.605	0.506	42	-1.109	1.379
Ogunkola (2001)	0.672	0.798	0.750	6	-0.256	1.692
Ott and Patino (2009)	-0.008	0.173	-0.008	2	-0.130	0.115
Subramanian (2003)	0.439	2.011	0.290	4	-1.399	2.574
Tuckson (2012)	0.109	0.435	0.068	15	-0.567	0.798

Table A3: Descriptive statistics on gravity model variables

Variable	Obs.	Mean	Std. Dev.	Min	Max
Exports (million USD)	47604	4.553	34.2	0	1460
Log GDP_i	46819	8.169	1.544	3.328	12.449
Log GDP_j	46850	8.203	1.597	3.328	12.449
Log distance	47604	7.960	0.694	5.089	9.187
Log area_i	47604	12.282	1.984	6.120	14.734
Log area_j	47604	12.296	1.972	6.120	14.734
Log population_i	47604	1.889	1.473	-2.743	4.975
Log population_j	47604	1.901	1.464	-2.743	4.975
Common currency	47604	0.090	0.286	0	1
Common language	47604	0.475	0.499	0	1
Border	47604	0.088	0.284	0	1
AMU	47604	0.008	0.087	0	1
COMESA	47604	0.034	0.182	0	1
ECCAS	47604	0.021	0.143	0	1
ECOWAS	47604	0.126	0.332	0	1
SADC	47604	0.030	0.170	0	1

Appendix 2:

The Computation of Fixed and Random Effects (REM)

The FEM assumes that the differences across studies can be explained only by a within-variation, as a result of sampling fluctuation. In the case of the FEM, the ES from each study is assumed to be a function of two components. That is, $\delta_i = \theta + \varepsilon_i$, where θ is the single population ES and ε_i is the deviation of the ES from the true population parameter. This true population ES is unknown but is estimated as a weighted average across the individual studies. The precision, which is the inverse of the square of the standard error (se) of the estimates, is used as weight (w_i), where $\hat{\theta} = \frac{\sum_{i=1}^{n} w_i \delta_i}{\sum_1^n w_i}$ and $w_i = \frac{1}{(Se(\delta_i))^2}$

In contrast to the FEM, the REM considers the differences in estimates to be explained by both within- and between-study variations. It assumes that the studies are random samples from a population of all possible studies. Technically, the REM conceptualizes the population distribution of the ES as derived from the normal distribution with mean 0 and variance (τ^2). The ES under the REM is decomposed into three components, $\delta_i = \mu + \xi_i + \varepsilon_i$, where μ is the mean of the distribution of the population of the effect sizes, ξ_i is the deviation (not due to sampling deviation) from the mean of the population ES and ε_i is the sampling deviation. In response to the two sources of imprecision, the population variability and sampling error, the REM incorporates an estimate of the between-study variation into the weights ($w_i{}^*$). The weight comprises of the population variance (τ^2) and the square of standard error (σ^2) of the specific estimates.

$$w_i{}^* = \frac{1}{\tau^2 + \sigma^2} \text{ , } where \ [Se(\delta_i)]^2 = \sigma^2, \tau^2 = \frac{Q - n + 1}{\sum_1^n w_i - \frac{\sum_1^n w_i{}^2}{\sum_1^n w_i}} \quad (1)$$

n is the number of observations and Q is a computed test statistic. The Q is computed as a weighted square of deviations of the individual ESs from their mean ($\bar{\delta}$). Mathematically, as follows:

$$Q = \sum_{i=1}^{n} w_i \, (\delta_i - \bar{\delta})^2 \quad (2)$$

The test is conducted by computing Q statistic, which has an χ^2distribution, with (n-1) degrees of freedom. If the computed Q statistic is greater than the critical value obtained, χ^2_{n-1}, then the result is statistically significant and you reject the null hypothesis of homogeneity and conclude heterogeneity. According to Higgins and Thompson (2002), the index is computed as follows:

$$\mathrm{I}^2 = \frac{\tau^2}{\tau^2 + \sigma^2} = \begin{cases} \dfrac{Q - n + 1}{Q}, & Q > n - 1 \\ 0, & Q \geq n - 1 \end{cases} \tag{3}$$