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Modeling and Estimation of Gravity Equation in the Presence of Zero Trade: A Validation of Hypotheses Using Africa's Trade Data

Fatima Olanike Kareem

Research Associate, GlobalFood Research Training Group 1666, Heinrich DukerWeg 12,
University of Goettingen, Germany. Email: fkareem@uni-goettingen.de



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Abstract

Gravity model of trade has emerged as an important and popular model in explaining and predicting bilateral trade flows. While the theoretical justification is no longer in doubt, nonetheless, its empirical application has however generated several unresolved controversies in the literature. These specifically concerns estimation challenges which revolve around the validity of the log linear transformation of the gravity equation in the presence of heteroscedasticity and zero trade observations. These two issues generate several challenges concerning the appropriate choice of the estimation techniques. This paper evaluates the performance of alternative estimation techniques in the presence of zero trade observations, checks for the validation of their assumptions and their behaviour in cases of departure from their assumptions, particularly the departure from the heteroscedasticity assumption. Analysis was based on a dataset of Africa's fish exports to the European Union, which contains about 70% zero observations. Given our dataset and the gravity equation specified, our results show that there is no one general best performing model, although most of the linear estimators outperform the GLM estimators in many of the robust checks performed. In essence, we find that choosing the best model depends on the dataset, and a lot of robust tests and advocate an encompassing toolkit approach of the methods so as to establish robustness. We concur with Head and Mayer (2013) that the gravity equation is indeed just a toolkit and cookbook in the estimation of bilateral trade flows.

Keywords: Gravity Equation, Heteroscedasticity, Zero trade flows, Estimation techniques

JEL Classification: C13 C33 F10 F13

1.0 INTRODUCTION

Gravity model of trade has emerged as an important and popular model in explaining and predicting bilateral trade flows. The model has been used to analyze the economic impacts of trade, investment, migration; currency union, regional trade agreements, etc. Its general acceptance as the workhorse of international trade and its proven popularity are primarily due to its exceptional success in predicting bilateral trade flows and the theoretical foundations given to it by both the old, new and 'new new' trade theories. However, prior to its general acceptance, there have been several criticisms about its lack of strong theoretical application, but which was later justified by the notable work of Anderson, 1979; Bergstrand, 1989; Deardorff, 1998; Helman and Krugman, 1985; etc, all of whom gave theoretical justifications to the model.

While the theoretical justification is no longer in doubt, nonetheless, its empirical application has however generated several unresolved controversies. These specifically concern the appropriate estimation technique and specification of the gravity equation, the former of which has generated several debates in the literature. The first concern is the estimation challenges which revolve around the validity of the log linear transformation of the gravity equation in the presence of heteroscedasticity and zero trade observations. The challenges posed by the validity of the log linear gravity equation arise from the conventional practice in the literature which is to log lineariz the multiplicative gravity equation. This is then estimated using ordinary least square (OLS) or by employing panel data techniques with the usual assumption of homoscedasticity across country pairs or countries (Gomez-Herrera, 2012). However, Santos Siliva and Tenreyro (2006, 2011), pointed out that due to the logarithmic transformation of the equation, OLS estimator may be inconsistent in the presence of heteroscedasticity and non-linear estimators should be used.

There are also challenges presented by the appropriate choice of the estimation techniques in the presence of zero trade values observations which is very common in trade data, and particularly pervasive in disaggregated data. Usually, the common practice in the literature in dealing with these zero trade observations are by employing the truncation method where the zero trade observations are deleted completely form the trade matrix, or censoring method where the zeros are substituted by a small positive constant an arbitrary small value. However, Flowerdew and Aitkin, 1982; Eichengreen and Irwin, 1998; Linders and Groot, 2006 and Burger et al., 2009 posit that these methods are arbitrary, are without any strong theoretical or empirical justification and can distort the results significantly, leading to inconsistent estimates. In addition, Heckman (1979) posit that if the zeros are not random, deleting can lead to loss of information; adding an arbitrary constant to the zero observations is tantamount to deliberately introducing measurement error which can lead to selection bias.

More appropriate estimation techniques are increasingly employed to deal with the estimation challenges posed by the logarithm transformation and zero trade flows issues in the context of gravity trade literature. The models proposed by Tobit (1959), Heckman (1979) and Helpman, Melitz and Rubinstein (2008) have all been used to deal with the problem associated with zero valued trade flows. For instance, the Tobit model was employed by Rose (2004) and Baldwin and DiNino (2002) to deal with the problem of zero valued trade flows which resulted either because the actual trade flows are not observable or due to measurement errors from rounding. However, several studies notable among which are Linder and De Groot (2006) argued that the appropriateness of using the Tobit model to estimate zero valued trade flows in a gravity model depends on whether rounding up of trade flows is important or whether the desired trade could be negative. They posit that the desired trade cannot however be negative since the zeros

do not reflect unobservable trade flow, therefore, one cannot censor trade flow from below it. Likewise, sample selection models were developed by Heckman (1979) and Helpman et al., (2008) to deal with selection bias resulting from the non-random elimination of zeros from the trade matrix. The sample selection models have also been criticized on the ground that it is difficult to satisfy the exclusion restriction. In addition, Santos Siliver and Tenreyro (2009) and Flam and Nordström (2011) show that Helpman et al., (2008) model does not control for heteroscedasticity which is usually pervasive in most trade data, consequently casting doubts on the validity of inferences drawn from the model.

However, in an influential paper, Santos Siliva and Tenreyro (2006) suggest that non-linear estimators, precisely the poisson pseudo maximum likelihood (PPML) should be used to deal with the zero trade observations as it provides unbiased and consistent estimates that are robust to the presence of heteroscedasticity in the data and naturally take care of the zero observations of the dependent variable. Nonetheless, the influential work of Santos Siliva and Tenreyro (2006) has generated a lot of controversies in the literature and alternative estimation techniques have been proposed to accommodate zero trade values in the data (c.f. Burger et al., 2009; Martinez-Zarzaso (2013); Helpman et al., 2008; Martin and Pham, 2008; etc). These studies aim to identify the best performing estimator, comparing alternative estimation techniques, but obtained divergent outcomes. This has led to several debates in the literature about which of the different alternative estimators perform best. For instance, Santos Siliva and Tenreyro (2006) propose the usage of the PPML as against the usual OLS technique, with the justification that it is consistent in the presence of heteroscedasticity and deals naturally with the zero trade flows. However, in an earlier paper - Martínez-Zarzoso, Nowak-Lehmann, Vollmer¹ (2007) and also more recently, Martinez-Zarzaso (2013) found that although the PPML is less affected by heteroscedastic compared to other estimators, nevertheless, the PPML estimator proposed by Santos Silva and Tenreyro (2006) is not always the best estimator as its estimates are outperformed by both the OLS and FGLS estimates in out of sample forecast.

In response to this, Santos Siliva and Tenreyro (2008) posit that although the other estimators might outperform the PPML in some cases, however, the PPML should be a benchmark against which other alternative estimators be compared due to its identified advantages. Study by Burger et al., (2009) has also challenged that of Santos Siliva and Tenreyro (2006). They posit that PPML is vulnerable to the problem of overdispersion in the dependent variable and excessive zeros and propose the use of the Negative Binomial Pseudo Maximum Likelihood (NBPML) to correct for the overdispersion in the dependent variable. In addition, they also found PPML and NBPML to be inconsistent in the presence of excessive zero trade observations and propose the usage of the Zero-inflated models which are Zero-inflated Pseudo Maximum Likelihood technique (ZIPML) and Zero-inflated Binomial Pseudo Maximum Likelihood technique (NIBPML) as they are noted to be consistent in the presence of excessive zeros. Similar result has been found by Martinez-Zarzaso (2013) and Martin and Pham, (2008), with the latter claiming that the Heckman model is appropriate for dealing with this issue.

To this end, the aim of this paper is to compare the performance of alternative estimation techniques in the presence of zero trade observations using African dataset across different product lines and check for the validation of their assumptions and their behavior in cases of

¹ Martinez et al (2007) was published in a journal in 2013 as Martinez-Zarzaso (2013).and henceforth we will mainly refer to Martinez-Zarzaso (2013).

departure from their assumption, particularly the departure from the heteroscedasticity assumption.

The focus of this study is methodological. As an empirical application, we investigate the impact of EU standards on Africa's fish exports using trade data from 1995 to 2012 across a sample of EU 27 and 52 African countries. Our choice of agricultural food trade hinges on the premise that agricultural trade is often dominated by zero trade flows, in contrast to industrial trade flows (Haq, 2012). Our study makes two important contributions to the existing methodological debate. First, most of the existing studies have investigated the performance of these estimators using developed and or developing countries dataset (Santos Siliva and Tenreiro, 2006; Martins and Pham, 2008, Staub and Winkelmann, 2012; Martinez-Zarzaso, 2013; etc). Our identified gap in this literature is that studies which have investigated the performance of the estimators using Africa's dataset are rare. However, Martinez-Zarzaso (2007) deduced that zero trade usually occurs among small or poor countries of which Africa belongs. Given the peculiarity of Africa's dataset in terms of missing data and or missing trade that usually characterize the above trade data problems which necessitates different estimators, we thus find it interesting to investigate the performance of alternative estimators given our particular dataset and add to the nascent of literature and debates on the best performing model.

The second novelty of our research is that to the best of our knowledge, there exist no study within the standard-agricultural-trade literature which investigated the impact standards exerts on trade by comparing the performance of a large number of alternative estimators (e.g. see Fontagne, Mimouni and Pasteels, 2006; Disdier and Fontagne, 2010, Xiong and Beghin, 2010, 2013; Drogue and Demaria, 2012; Winchesta et al, 2012, Shepherd and Wilson, 2013; etc). Our analysis departs from existing studies which usually consider a limited number of estimation techniques (PMLs, Heckman and OLS). We consider a very much larger pool of estimators compared to past studies.

The rest of the paper is structured as follows. The next section reviews the theoretical foundations of the gravity model. Section 3 provides a short discussion of various gravity model estimation techniques and the challenges presented by them in the presence of heteroscedasticity and zero trade flows; and also reviews related empirical literature. Section 4 provides the methodology and describes the data, while section 5 discusses the results. The final section concludes.

2.0 THEORETICAL LITERATURE

The gravity equation were first used in the nineteenth century by Ravenstein (1885) and then by Zipf (1946) contrary to what a majority of trade economists believe. However, the formal usage of the model dated back to Tinbergen (1962) and Pöyhönen (1963), both of whom suggest that the functional form of Newtonian gravity could also be used to explain bilateral trade flows between distant countries. This notion of gravity equation is based on Isaac Newton's proposition of the law of universal gravitation which states that the gravitation force between two objects 'i' and 'j' is directly proportional to the multiplication of the masses of the objects and inversely related to the distance between these two objects. The Newtonian gravity equation is given as:

$$GF_{ij} = C \frac{M_i M_j}{D_{ij}} \dots\dots\dots(1)$$

Where GF is the gravitational force between two masses; C is the gravitational constant; M_i and M_j are the masses and D is distance between the two masses.

The early version of the model may also be expressed roughly in the same notation as:

$$X_{ij} = \beta_0 (Y_i)^{\beta_1} (Y_j)^{\beta_2} (D_{ij})^{\beta_3} \mu_{ij} \dots\dots\dots(2)$$

Where X_{ij} is the value of bilateral import\exports in current dollars; Y_i, Y_j are respectively the exporters and importers economic masses proxy by their income; D_{ij} is the distance between country-pairs, μ_{ij} is the disturbance term; and β_s are the unknown parameters of the equation.

This specification was first used by Tinbergen (1962) and Pöyhönen(1963) and later used by other scholars. However, Linnemann (1966) used the same specification but augmented it with importer and exporter population. His theoretical basis for the gravity equation was based on the Walrasian general equilibrium framework and the equation is derived as a reduced form equation from a four-equation partial equilibrium model of import demand and export supply function. Here, prices are excluded as they only adjust to equalise demand and supply (Linnemann 1966; Leamer and Stern, 1970). Leamer and Stern, (1970) however argued that this theoretical approach is loose, it lacks a compelling economic justification and fails to explain the multiplicative functional form of the gravity equation. Subsequently, Leamer developed a hybrid version of the gravity equation, however, it has also been faulted as being atheoretical.

Strong criticisms were made against gravity equation due to its lack of strong theoretical foundations; and this made the model to be neglected between late 1960s and late 1970s. Nevertheless, in recent years, the gravity model has again become very popularity in explaining trade relations due to two factors. One of these is due to the rigorous theoretical foundation given to it with the advent of trade theories especially the new trade theory. The second and most important, it is now very popular due to its notable empirical success in predicting bilateral trade flows of different commodities under different situations (Deardorff, 1984; Leamer and Levinsohn, 1995). This is the reason that most recent studies in trade often adopt the model in explaining bilateral, multilateral and regional trade agreements. In fact, the use of the union model has been applied beyond trade; evidence has shown that it has been applied to currency union (Rose 2000, Baldwin, (2006) Frankel, 2009), health (Manning and Mullahy, 2001; Staub and Winkelmann, 2012), FDI (Linnemann, 1966; Egger, 2004, 2007; Egger, & Pfaffermayr, 2004) and so on. Thus, the equation has now become a toolkit in international economics.

2.1. Theoretical Foundations for the Gravity Equation

The theoretical basis for the gravity model was first formally introduced by Anderson (1979) and later extended by Bergstrand (1985, 1989; 1990), Deardorff (1998), Eaton and Kortum (2002), and Anderson and Van Wincoop, (2003) etcetera. Specifically, the gravity equation has been derived under the classical or standard trade theory, the new and new new trade theories. Under the standard trade models, the explanations and pattern of international trade rely heavily on comparative advantage and differences in production technology (Ricardian model of trade) and differences in relative factor endowments (Heckcher-Ohlin model). These models assume perfect competition and therefore constant returns to scale in production and no

attention is paid to increasing returns to scale, imperfect competition and transport costs. However, with the advent of new trade theories, the equation has also been derived under imperfect competition markets and increasing returns to scale (Helpman and Krugman approach).

2.2.1 New Developments in the Theoretical Foundation

After more than two decades of an influx of models providing theoretical justification for the empirical success of the gravity equation, emphasis thereafter turned to ensuring that the empirical results of the gravity equation is well defined on theoretical grounds. One important contribution in this regard relates to the structural form of the equation and the implication of misspecification or omitted variable bias. These relate to way trade costs and firm heterogeneous behavior is incorporated into the gravity equation. The work of Anderson and vanWincoop (2001 or 2003) and Helpman, Metlitz and Rubeinstein (2008), etc are deemed to be influential here.

Modeling Trade Costs - Multilateral Trade Resistance

The multilateral trade resistance trade cost was discovered by Anderson and van Wincoop (2001) in his seminar paper following the controversial study by McCallum (1995) who find that in 1988, US-Canadian border led to a trade between Canadian provinces which is 22 (2200%) times more than trade between the US states and the Canadian provinces. This is termed the '*border puzzle*'² or a home bias in trade puzzle, which makes it one of the six puzzles of open macroeconomics (Obstfeld and Kenneth Rogoff, 2001).

Motivated by the resulting border puzzle of McCallum (1995), Anderson and van Wincoop (2001, 2003) gave the gravity model a new theoretical underpinning to explain and solve this border puzzle effect by incorporating the multilateral resistance term. They posit that McCallum's ration of inter-provisional trade to province-state trade is very large because of omitted variables bias, (multilateral resistance terms term) and the small size of the Canadian economy. They however got a smaller border effects than in McCallum (1995) after controlling for multilateral trade resistance in their regression model.

Extending Anderson 1979 theoretical derivation, they derive that economic distance between countries i and j is not only determined by a bilateral resistance term between these two countries as shown by previous derivations but also in relation to a weighted average of economic distance to all other trading partners of the given country. The latter is what they termed the multilateral resistance term and the theoretically appropriate average trade barrier.

They employ a monopolistic competition framework which is built on the Armington assumption that each country produce differentiated goods and trade is therefore driven by consumers' love for varieties such that all domestic and foreign goods are imported by the variety loving consumers. Optimizing consumers across countries and this is captured by CES preference. Goods are also assumed to be differentiated by region of origin such that each country specialize in the production of only on good which is fixed in supply; and all goods produced by both domestic and foreign firms are consumed by the variety loving consumers. A

²Border puzzle is the tendency for a country to trade with and buy domestic products originating from domestic home country - a strong preference or bias for domestic goods. This phenomenon is termed border puzzle by McCallum (1995) and arises because countries borders are supposed to have a significant effect on the trade patterns between the countries especially if the countries are similar in terms of same language, culture and economic institutions as in the case of the US and Canada. However, the estimated patterns of trade indicates strong inter-provincial trade and less province-state (international trade) between Canada and the US, implying that national borders constraint trade among countries even though the countries are similar to one another (McCallum, 1995).

key feature of the model is the introduction of exogenous bilateral trade costs into the gravity model. This incorporation of trade costs, which are directly observable makes, ensure that prices of the goods can differ across countries, and non-price equalisation implies that elasticity of substitution across products is non-unitary which is in contrast to Anderson (1979) which assumes a unitary elasticity of substitution.

The equilibrium condition results in a general equilibrium model and assuming trade barriers are symmetric and imposing a market clearing condition, yields a micro-founded gravity equation which relates bilateral trade flows to size and trade costs where the trade costs are decomposed into 3 components: the bilateral trade barriers between exporting country i and importing countries j ; exporting country's resistance to trade with all countries (outward multilateral resistance); and importing country's resistance to trade with all countries (inward multilateral resistance). The resulting micro-founded gravity equation then relates bilateral trade flows to country's size, bilateral trade barriers and multilateral trade resistance variables. Specifically, it predicts that bilateral trade flow is explained by income of exporters and importers, an elasticity of substitution across goods which is greater than unity, bilateral trade costs, and exporters and importers prices indices which they termed multilateral trade resistance term (ratio of outward to inward multilateral trade resistance) also known as relative trade term or average trade costs.

Sequence to Anderson and van Wincoop (2001) influential seminar paper, Feenstra (2002) also noted the exaggerated and biased estimate of the Canada-US border effects in McCallum 1995. To avoid this bias, he re-derived the gravity equation allowing for trade barriers (such as tariff and transport costs) across countries such that they have different prices. He therefore deviated from the conventional gravity equation (like that of McCallum, 1995) which do not incorporate price indexes, which have the effect of overstating the border effect for Canada and understating it for the US. According to Feenstra (2002), with the introduction of border effects (tariffs and transport costs), price equalization across countries no longer hold.

Following Anderson (1979), Feenstra (2002) also derived a gravity equation from a monopolistic competitive model in which consumers face CES utility function. To allow for non-factor price equalization across countries, he made a further assumption. Each country is assumed to produce unique product varieties with the products exported by the exporting country selling for the same price in the foreign importing country, where these prices are sold in importing market inclusive of transport costs while prices in exporting countries are exclusive of any transport costs (fob). The optimizing the utility of the representative consumer in destination countries and solving the equation further gives the gravity equation which relates total bilateral trade values to aggregate income in destination country, number of products, relative price index of each country and elasticity of substitution factor.

Novy (2011) also derived a gravity equation which incorporates multilateral trade resistance. Building on Anderson and van Wincoop (2003) gravity framework, he derived an analytical solution for the multilateral trade resistance (both time varying and observable multilateral resistance variables) from which bilateral trade costs can be directly predicted. He noted that there are some drawbacks in Anderson and van Wincoop (2003) assumptions used in solving the multilateral resistance terms, as they abstract strongly from reality. For instance, they assume bilateral trade costs to be function of two trade costs proxies – bilateral geographical distance and a border barrier, and further assume that these bilateral trade costs are symmetric for country pairs. He noted that drawbacks arise, first, because there is the possibility of trade cost function being mis-specified as it omits an important trade cost – tariff; and secondly,

trade costs might turn out to be asymmetric as countries impose higher tariffs than others. Novy therefore overcome these drawbacks by deriving an analytical solution for the multilateral resistance variables using a method that neither imposes symmetric trade costs nor any particular trade cost function. This gives a micro-founded gravity equation which allows for unobservable trade costs.

New New Trade Theory

Another major area of new contribution relates to methodological issue associated with the presence and behavior of heterogeneous firms operating in international markets which was spearheaded by Melitz (2003) and Bernard et al., (2003). Firm heterogeneity arises since not all existing firms in a country exports, as only a minority of these firms participate in international market (Bernard et al, 2003; Mayer and Ottaviano, 2008). Furthermore, not all exporting firms export to all the countries in the rest of the world; they are only active in just a subset of countries and may choose not to sell specific products to specific markets (or their inability to do so). The reason for the heterogeneity in firm behavior is because fixed costs are market specific and higher for international trade than for domestic markets. Thus, only the most productive firms are able to cover these costs, and firms' inability to exports may be due to the high cost involved. Consequently, the bilateral trade flows matrix will not be full as many cells will have zero entries. This case is seen at the aggregated level of bilateral trade flows but more often in greater levels of product data disaggregation such as HS6 and HS8.

The prevalence of zero bilateral trade flows has important implication for modeling the gravity equation as zero trade between several country-pairs might signal a selection bias problem. In addition, the observed zeros might contain important information about the countries (such as why they are not trading) which should be exploited for efficient estimation. Thus, more recent waves of theoretical contribution relate to deriving the gravity equation which allows for firm heterogeneity into the equation and the development of an influx of estimation techniques that would take care of the zero trade records.

Standard gravity equation usually neglect the issue of the prevalence of zero bilateral trade flows and predict theory consistent with only positive bilateral trade flows. However, Helpman, Melitz and Rubinstein (2008); Novy (2011, 2012), etc derived theoretical gravity equation which highlight the presences of zero trade records and gives theoretical interpretations for them. The new new trade model of international trade with firm heterogeneity which is spear-headed by Metlitz (2003) is usually adopted in giving the gravity equation theoretical basis which is elaborated below.

Helpman et al. (2008) argue that "by disregarding countries that do not trade with each other, these studies give up important information contained in the data" (Helpman et al. 2008 p442), and that symmetric relationship imposed by the standard gravity model biases the estimates as it is inconsistent with the data. To correct for this bias, Helpman et al (2008) provides a theoretical gravity equation that explains/incorporates firm heterogeneity and positive asymmetric and was thus able to predict both positive and zero trade flows between country-pairs. Given firm level heterogeneity, they assume products are differentiated and firms are faced with both fixed costs and variable costs of exporting. Firms vary by productivity, such that only the more productive firms find it profitable to export; with the profitability of exports varying by destination. Since not all firms found it profitably, this gives rise to positive and zero trade flows across country-pairs. Furthermore, this difference in productivity gives rise to asymmetric positive trade flows in both directions for some pairs of countries. These positive

asymmetric trade and zero bilateral trade flows then determine the extensive margin of trade flows (number of firms that exports). Moreover, given that firms in country '*j*' are not productive enough to enable them profitably export to country *i*, this implies that will be zero trade flows from country *j* to *i* for some pairs of countries. This generates a model of firm heterogeneity that predicts zero trade flow from countries *j* to *i* but positive exports from country *i* to *j* for some pairs of countries, and zero bilateral trade flows between countries in both direction.

Sequent to Helpman et al. (2008), others have also derived the gravity equation allowing for firm heterogeneity (c.f. Chaney, 2008; Melitz and Ottaviano, 2008; Chen and Novy 2011). For instance Chaney (2008) derives an industry level gravity equation using a model which assume firm level heterogeneous productivity across firms and fixed costs of exporting. Chen and Novy (2011) however argued that apart from variations in trade costs across industries, industry specific elasticities of substitution are also important in capturing the cross industry variations. So they derive a model that allows for both industry specific bilateral trade costs and industry specific elasticities of substitution. Employing the monopolistic competition framework used in Anderson and van Wincoop (2004) which allows for only heterogeneous cross country trade costs, they also included heterogeneous elasticities of substitution across industries in the model, and generate a micro-founded gravity equation of bilateral trade flows that controls for cross industry heterogeneity but nets out multilateral resistance terms.

Chen (2012) deviate from the standard gravity equation that assumes CES, which trade costs have similar effects across country pair, and this gives rise to gravity equations with constant elasticity of trade with respect to trade costs. This implies that *ceteris paribus*, a change in trade cost has similar proportionate effect on bilateral trade flows irrespective of whether the tariffs faced by the countries were initially low or high or whether a given country pair traded a lot or little. He justified that in reality, trade costs have heterogeneous trade impeding impact across countries as the effect on trade flows depend on how intensive pairs trade with each other; the trade flows of exporting countries that provide only a small portion of the destination country's total import is more sensitive to bilateral trade costs. Likewise, trade is more sensitive to bilateral trade flows for countries that import very little from a given exporter. Consequently, trade costs might have a heterogeneous impact across country pairs, with some trade flows can be zero. Based on this justification, he then use the translog gravity equation in which trade costs have a heterogeneous trade impeding effect across country pairs, which is also consistent with zero trade demand.

In sum, gravity equation can arise from a wide range of trade models both standard, new and new new trade theories. They are usually offered as theoretical substitutes and the choice of the equation depend on the preferred set of assumptions and models (Bier and Bergstrand, 2001). Nonetheless, there are some differences in the underlying assumptions and models and such differences could probably explain the various specifications in the literature and the diversity in the empirical results (Martinez-Zarzoso and Nowak-Lehmann, 2002). While the theoretical basis is no longer in doubt, emphasis is now on ensuring that its empirical applications is well rooted on its theoretical ground and that it can be linked to anyone of the available and appropriate theoretical frameworks. However, irrespective of the theoretical framework adopted, most of the subsequent justifications of the gravity equations are variants of the one first derived in Anderson (1979). Thus, in this study, we rely mainly on Anderson and van Wincoop (2003) which is similar to Anderson (1979) except for the multilateral trade resistant.

3.0 EMPIRICAL LITERATURE

The gravity model is very popular in explaining trade relations. First, this is due to the rigorous theoretical foundation given to it with the advent of trade theories especially the new trade theory. Second and more important, this is due to its empirical success in the analysis of foreign trade relations. However, in spite of the popularity it enjoys, there are still questions about the proper specification of the model as well as the proper econometric estimation technique(s) to use. This session therefore shed light on the various estimation techniques used and the specification issues involved in gravity modeling. Particular attention is focused on the problems or and advantages of each techniques in the presence of zero trade flows in the data, the occurrence of which is prominent as a result of disaggregated dataset in which over 50% of trade values are found to be zero. The session ends by reviewing the techniques employed in empirical studies of standard-trade literature.

3.1 ESTIMATION ISSUES IN GRAVITY MODELLING

Early empirical studies rely on cross sectional data to estimate the gravity model, thus the economic framework for the model was cross-sectional analysis, (c.f. Anderson, 1979; Bergstrand, 1985, 1989; McCallum, 1995; and Deardorff, 1998; etcetera). For such cross-sectional analysis, the ordinary least square (OLS) estimation technique or pooled OLS technique is normally employed. However, the traditional cross-sectional approach is affected by severe misspecification problems and thus previous estimates are likely to be unreliable (Carrère, 2006). This is because the traditional cross sectional gravity model usually include time invariant variables (e.g. distance, common language, historical and cultural dummies, border effects), but the model suffers from misspecification problems as it fail to account for country specific time invariant unobservable effects. This unobservable country specific time invariant determinants of trade are therefore captured by the error term. However, these unobserved variables are likely to be correlated with observed regressors and since OLS technique is usually used, this renders the least square estimator to be inconsistent, which makes one its classical assumptions invalid. In addition, OLS does not control for heterogeneity among the individual countries, which has the potential of resulting into estimation bias as the estimated parameters may vary depending on the countries considered. Therefore, estimating cross sectional formulation without the inclusion of these country specific unobservable effects gives a bias estimate of the intended effects on trade. This renders the conclusions on cross sectional based trade estimates problematic (*ibid*).

However, over the last decade, there is the increasing use of panel data in gravity modeling and the use of panel econometric methods (c.f. Egger, 2000; Rose and van Wincoop, 2001; Baltagi, 2003; Egger and Pfaffermayr, 2003; Egger and Pfaffermayr, 2004; Melitz, 2007; and many others). The panel specification is much more adequate as the extra time series data points gives more degree of freedom, results in more accurate estimates. A unique advantage of panel data is that the panel framework allows the modeling of the evolvement of variables through time and space which helps in controlling for omitted variables in form of unobserved heterogeneity which if not accounted for can cause omitted variable bias (Baltagi, 2008). In addition, with panel data, the time invariant unobserved trade effects can easily be modeled by including country specific effects such as time dummies, and thus avoiding the consistency issue mentioned above.

With the availability of panel data, the two common techniques used in fitting the data are the fixed effects and random effect estimation techniques, where the choice between the two hinges on their a priori assumptions. The fixed effect assumes that the unobserved heterogeneity is correlated with the error term. In contrast, the random effect assumes that the

unobserved heterogeneity is strictly exogenous i.e. it does not impose any correlation between the unobserved heterogeneity (individual effects) and the regressors. Under the null hypothesis of zero correlation, the random effect model is efficient; both models are consistent, but the random model is more consistent. If however the null hypothesis is rejected, the fixed effect is consistent and the random effect is neither consistent nor efficient. There are however, some drawbacks in the fixed effect model in the sense that all time invariant explanatory variables (are deemed to be perfectly collinear with the fixed effects) would be dropped from the model. Consequently, fixed effect model eliminates some important theoretically relevant variables from the gravity equation which are distance, common language, common borders, and the effects of these variables cannot be established. In addition, studies have also apply the OLS technique to panel data. However, pooled OLS can only give precise estimators and test statistics with more power if the relationship between the dependent variable and the regressors remain constant over time.

Early gravity model estimation technique was to estimate the equation by least squares, where the model is usually log linearized as a common practice. Their position is that for the validity of a log-linear gravity model hinges on the homoscedastic assumption, as the error term and the log must be statistically independent of the regressors. However, in recent times, Santos Silva and Tenreyro, (2006) have identified flaws with this practice. Their position is that due to the nature of trade data that are intrinsic to heteroscedasticity and pervasive zero trade observation, log linearizing the gravity equation and then applying OLS is problematic.

First, problems arise in logarithmic transformation due to heteroscedasticity which is usually present in trade data. As noted by Santos Silva and Tenreyro (2006) in their influential paper, the common practice of log linearizing the gravity equation and then estimating using OLS is inappropriate because, expected values of the log linearized error term will depend on the covariates of the regression and hence OLS will be inconsistent even if all observations of the dependent variables are strictly positive. This is because logarithmic transformation of the gravity model changes the property of the error term. In other words, OLS will produce consistent estimates as long as the error term (ε_{ijt}) of the log linear specification ($\ln \varepsilon_{ijt}$) is a linear function of the regressors, i.e., if $E[\ln(\varepsilon_{ijt} | x_{ijt})] = 0$, which is the homoscedasticity assumption. However, logarithmic transformation generates estimates of $E(\ln \varepsilon_{ijt})$ and not $\ln E(\varepsilon_{ijt})$, but $E(\ln \varepsilon_{ijt}) \neq \ln E(\varepsilon_{ijt})$, where $\ln E(\varepsilon_{ijt} | x_{ijt}) = 0$; $E(\ln \varepsilon_{ijt} | x_{ijt}) \neq 0$, which is the well-known Jensen's inequality³.

Consequently, due to Jensen's inequality, the error term (ε_{ijt}) is not equal to the log of the error term ($\ln \varepsilon_{ijt}$) as the error terms in the log linear specification of the gravity equation are not statistically independent of the regressors but are rather heteroskedastic, leading to inconsistent estimates of the elasticity coefficients. Given this Jensen's inequality, Santos Silva and Tenreyro (2006) argue that the log linear transformation of the gravity model is intrinsic to heteroscedasticity and applying OLS results into biased and inefficient estimates. They argue

³ Jensen's inequality is named after Johan Jensen, the Danish mathematician who in 1906 discovered that: the secant line of all convex function (i.e., the means of the convex function) lies above graph of the function (i.e., the convex function of the weighted means) at every point. The reverse is true for a concave function. His inequality has appeared in many contexts and an example in this case is the arithmetic mean inequality. Thus, in simplified terms, his inequality states that the convex (or concave) transformation of a mean is less or equal to (greater or equal to) the mean after a convex (concave) transformation. Thereafter, Economists have adopted his intuition to show that the logarithm transformation of an equation generates the expected value (mean) of the logarithmic transformation of the dependent variable $E(\ln Y_{ijt})$ and not the logarithm of the mean of the dependent variable $\ln E(Y_{ijt})$; and $E(\ln Y_{ijt}) \neq \ln E(Y_{ijt})$.

that even though Economists have long known about Jensen's inequality and that the concavity of the logarithm function could create a downward bias when employing OLS, this important drawback has however been overlooked in bilateral trade studies. They confirm their argument as they found evidence of the presence of heteroskedasticity and inconsistency in the normal log-linear representation of the gravity model; which renders the estimates of elasticity obtained from least squares estimation technique to be both inefficient and inconsistent.

Second and more importantly is the presence of zero trade flows in the trade matrix and the appropriate estimation technique. While the Newtonian gravity theory from which the gravity model of trade was derived allows for very small gravitational force but not zero force, however, in trade, there are frequent occurrences of zero⁴ valued bilateral trade flows and the practice of estimating the log linear gravity model in the presence of such zero trade flows implies both theoretical and methodological problems; especially in cases where the presence of such zero values are excessive. In estimating the gravity model, the gravity model is log linearized and estimated using these linear regression techniques. However, given the predominance of zero trade records in the trade matrix, particularly at the more disaggregated level, where zero records can account for about 50% of trade flows, the logarithm transformation of the dependent variable is therefore problematic. This is so because the logarithm of zero is indeterminate or not feasible.

However, the common practice in the literature employed to deal with the problem of zero records in the data are the truncation and censoring methods and thereafter applying linear estimation techniques. In the case of truncation method, the zero valued trade flows are dropped completely from the trade matrix, whereas, the censoring method involves substituting the zeros by a small positive arbitrary value. These methods are however arbitrary and are without any strong theoretical or empirical justification and can distort the results significantly, leading to inconsistent estimates (c.f. Flowerdew and Aitkin, 1982; Eichengreen and Irwin, 1998; Linders and Groot, 2006; Burger et al., 2009; Gomez-Herrera, 2012). In addition, Flowerdew and Aitkin⁵ (1982) show that the results are sensitive to (small) differences in the constant substituted, which can cause serious distortion in the results. Eichengreen and Irwin (1998) noted that deleting these zero values led to loss of information as important information on the zero trade levels is left out of the model and this can generate biased results if the zero trade flows are not randomly distributed; while Heckman (1979), Helpman et. al, (2008) posit that omitting these zero trade records can result into sample selection bias. The loss of information is said to reduce efficiency and omission of data produces biased estimates (Xiong and Beghin, 2011; Gomez-Herrera, 2012). In addition, Xiong and Beghin (2011) noted that deleting the zero trade observations prevents the possibility of exploring the extensive margin of trade – the creation of new bilateral trade relations, which implies that estimates are conditioned on trade that already took place – the intensive margin of trade. They concur that ignoring zeros limits the economic interpretation of the model as nothing can be said on the implication for new trade.

Likewise, Linder and Groot kicked against truncating and censoring and argued that zero trade observation may provide important information for understanding the bilateral trade patterns and therefore should not be eliminated aprior. Disregarding the zeros trade flows can bias the results if they do not randomly occur. This is because zero trade flows provide information

⁴Frankel (1997) argued that these zero values arises as a result of lack of trade between countries, or from rounding errors when trade between countries does not reach a minimum value or can arise when they are rounded-down as zero, it can also results from measurement errors where observations are mistakenly recorded as zeros.

⁵They vary the substituted constant between 0.01 and 1 and found that the regression coefficient decreases with the size of the chosen constant.

about the probability to engage in bilateral trade. thus, if distance, low levels of GDP, the lack of historical or cultural links, etcetera makes trade to be non-profitable, thereby reducing trade or bringing about no trade, then eliminating zero flows from the analysis is tantamount to sample selection bias and applying OLS will lead to underestimating of the gravity equation coefficients (downward bias).

Therefore, in recent years, attention has been on the appropriateness of the estimation technique especially those relating to the problems of zero trade costs and logarithmic transformation of the gravity equation, and the constant emphasis on the inappropriateness of linear estimators in taking care of these two problems. Consequently, more appropriate estimation techniques are being increasingly employed to deal with these two issues in the context of gravity trade literature. The Tobit and Probit models, truncated regression, Poisson and modified Poisson models, Nonlinear Least Square (NLS), Feasible Generalized Least Square (FGLS) and the Helpman, Melitz and Rubinstein (2008) approach have all been used to deal with the problem associated with log normal formulation and the excessive zero valued trade flows.

Early studies have relied on the Tobit model to deal with the zero trade problems. For instance, the Tobit model has been employed by Rose (2004) and Andersen and Marcoiller (2002) to deal with the problem of zero valued trade flows that resulted either because the actual trade flows are not observable or due to measurement errors from rounding. The Tobit estimator is applied to fit dataset when outcome/data are only observable over some range. It is applied in cases of measurement errors (e.g rounding up) or when actual outcomes cannot seem to reflect the desired outcomes. The Tobit censoring method involves rounding (censoring) part of the observation to zero or rounding up the zero trade flows below some positive value.

Nevertheless, (Linder and Groot, 2006) have debated on the appropriateness of using the Tobit model to the Tobit model to fit zero valued trade flows in a gravity model will depend on whether the desired trade could be negative or whether rounding up of trade flows is important. Their argument is that in the gravity model, the zero trade flows cannot be censored at zero as the desired trade cannot be negative in the gravity equation; this can only occur if the GDP of one or country pair is equal to zero which is unlikely in real life. They further argue that censoring at a positive value is not also appropriate. The intuition is that the UN COMTRADE reports trade values, even for very small values (up to \$1), indicating that rounding to zeros is not an important cause of zero observation as most zeros are caused by economic reasons such as lack of profitability .This implies that zero trade flows is likely to occur from binary decision making about the profitability of engaging in trade, and not from rounding up (censoring), thus the model might not be appropriate for taking care of zero trade flows. In addition, Frankel (1977) and Rose (2000) noted that the Tobit estimator involves an artificial censoring of positive albeit small trade values, however, the trade flow is subject to measurement errors, and they may have a high influence on the regression results.

Furthermore, Martin and Pham (2008) show that although both truncated OLS and censored Tobit model lead to bias results but the censored method generally produced much worse results in comparison to the truncated method, and suggested that Eaton and Tamura (1994) threshold Tobit model gives the lowest bias and outperform all other estimators in a simulation exercise. However, in contrast, in a simulation exercise, Santos Silva and Tenreiro (2011) found the Tobit model of Eaton and Tamura (1994) to have large bias, which increases with sample size, which also confirm its inconsistency as an estimator.

Attention has also been shifted to the use of the Poisson and the modified Poisson specifications of the gravity model. Santos Silva and Tenreyro (2006; 2011) used the Poisson Pseudo Maximum Likelihood (PPML) method to deal with the zero valued trade flow and the logarithm transformation. According to them, in the presence of zero valued observations and also due to the logarithm transformation of the gravity equation, OLS (both truncated and censored OLS) are inconsistent and have very large bias which do not vanish as the sample size increase which confirm that they are inconsistent (Santos Silva and Tenreyro 2011). However, the PPML estimates the gravity equation in levels instead of taking its logarithms and this is said to avoid the problem posed by using OLS under logarithm transformation. According to them, this model is appropriate: first, the Poisson model takes account of observed heterogeneity. Second, the fixed effects PPML estimation technique gives a natural way to deal with zero valued trade flows because of its multiplicative form. Third, the method also avoids the under-prediction of large trade volumes and flows by generating estimates of trade flows and not the log of the trade flows. In their 2006 influential paper, they find the PPML estimator, which need not be log-linearized, to be the best performing estimator that naturally deal with zero trade flows, consistent and gives the lowest bias among the other estimators. They therefore suggest it as the new workhorse for the estimation of the typical constant elasticity models, such as the gravity model.

However, their influential paper has however generated some controversies in the literature (c.f. Martinez et al., 2007; Martin and Pham 2008; Burger et al., 2009; etcetera). For instance, Burger et al. (2009) identified some important limitations of the PPML model. They noted that the model is vulnerable to the problem of overdispersion in the dependent variable and excess zero flows. They posit that the model only takes account of observed heterogeneity and not unobserved ones and this is an important limitation of the PPML model. While an important condition of the PPML is the assumption of equidispersion (the conditional variance is equal to the conditional mean) in the dependent variable, however, due to the presence of unobserved heterogeneity which are not accounted for in the model, there is an over-dispersion in the trade flows (dependent variable). The over-dispersion is said to generate consistent but inefficient estimates of trade flow (Burger, et al. 2009; Turkson, 2010).

Contrary to Burger et al. (2009) who noted that the model is vulnerable to the problem of overdispersion in the dependent variable and excess zero flows, which generate consistent but inefficient trade estimates, Santos Sliver and Tenreyro (2011), find that PPML is consistent and generally well-behaved even in the presence of overdispersion in the dependent variable (i.e. when the conditional variance is not equal to the conditional mean) and that the predominance of large proportion of zeros does not affect its performance. In addition, Soren and Bruemmer (2012) find that the PPML performs quite well under over-dispersion, and show that the PPML is well-behaved under bimodal distributed trade data.

Nonetheless, attempts have also been made to correct for the over-dispersion in the dependent variable and the vulnerability of the PPML to excessive zero flows using other estimation techniques apart from the PPML. These are the Negative Binomial Pseudo Maximum Likelihood (NBPML) and the Zero-inflated models which are Zero-inflated Pseudo Maximum Likelihood technique (ZIPML) and Zero-inflated Binomial Pseudo Maximum Likelihood technique (NIBPML) (Burger et al. 2009). They posit that the NBPML corrects for the overdispersion the estimator incorporates unobserved heterogeneity into the conditional mean and thus, takes care of unobserved heterogeneity. However, an important drawback of the NBPML and PPML relates to the excessive number of zero in the observation which means that the number of zero flows is greater than what the models predicts; where excessive zeros

is said to be derived from the ‘non-Poissonness’⁶ of the model (Johnson and Kotz, 1969). Thus, Burger et al. (2009) posit that even though the Poisson model and the NBPML model can technically handle with zero flows, both models are however not well suited to handle cases where the number of observed zero valued trade flows is greater than the number of zeros predicted by the model.

They posit that the zero inflated models (ZIPML and ZINBPML) perform better as correct for excess zeros and overdispersion in the dependent variable. They also noted that zero-inflated models has an added advantage as they theoretically well suited in modeling the origin of zero counts because the models account for two different types of zero trade flows, which are countries that have never trade (the non-poisson group), implying a data that strictly have zero counts; and countries that presently do not trade but potentially could, i.e. those that have a non-zero probability of having non-zero counts (the poisson group⁷). Thus, these models make allowances for the possibility to separate the probability to trade from trade volume as it provides additional information on the causes of the probability of the different kinds of zero valued flows. Given these, Turkson (2011) argued that the choice of the model to use will depend on whether the sample has excessive zero trade flow or not. However, Burger et al. (2009) posit that the Poisson model and the NBPML model are not well suited to handle cases where the number of observed zero valued trade flows is greater than the number of zeros predicted by the model.

Contrary to Burger et al. (2009), Staub and Winkelmann (2012) however find that the PPML is consistent even when zeros are excessive. They also show that both ZIPML and ZINBPML are inconsistent if the underlying assumptions of the distribution of model are violated, i.e. if the models are misspecified. They instead recommend the use of zero inflated Poisson Quasi Likelihood (PQL) estimator which was shown to be consistent in the presence of excessive zeros and it is unaffected by unobserved heterogeneity and found to robust to misspecification as it consistently estimate the regression coefficients irrespective of the true distribution of the counts while ZIPML and ZINBPML demonstrate considerable bias in medium sample. They also noted that the PQL can be less efficient compared to zero inflated estimators if the zero inflated model is correctly specified.

Similar to Burger et al., (2009), Martinez-Zarzoso (2013) also find out that the PPML estimator proposed by Santos Silva and Tenreyro (2006) is not always the best estimator as its estimates are outperformed by both the OLS and FGLS estimates in out of sample forecast. In addition, the PPML assumption regarding the pattern of heteroscedasticity is rejected by the data in most cases. However Santos Silva and Tenreyro (2008) responded by justifying the use of PPML as the best estimator in the context of gravity model, but also acknowledged that PPML estimator can be outperformed by other estimators in some cases.

Furthermore, Martinez-Zarzoso (2013) also finds the PPML to be outperformed by both the OLS and FGLS estimates in out of sample forecast and deduced that it is not always the best estimator. She finds that PPML assumption regarding the pattern of heteroscedasticity is rejected by the data in most cases. She opined that even in the presence of unknown form of

⁶Burger et al. (2009) identified that one important cause of non-Poissonness is when some zeros in the observation are produced by a different process compared to the remaining observations (including some other zeros)

⁷The zero inflated models consider two different groups within the population: the poisson group and the non-poisson group. The non-poisson group are countries which have strict zero probability of trading but do not trade at all. The non-poisson zeros might be caused by lack of trade due to bans or other trade embargoes or simply the lack of resources. The poisson group consist of those countries with non-zero probability to trade and are actually trading, and countries that have non-zero probability to trade but however do not trade. The poisson zeros might be caused by huge distance or large differences in country pairs preferences and specialization.

heteroscedasticity, FGLS can still be applied as FGLS is an efficient estimator within the class of least squared estimator, but the variance of the disturbances should then be re-estimated to correct for heteroscedasticity errors. They pointed out that FGLS is well suited to estimating parameters in the presence of heteroscedasticity, so, the comparison⁸ of the best performing estimator should be between FGLS and the class of generalized linear models⁹ (GLM) such as the Non-linear least square (NLS), Gamma Poisson Maximum Likelihood (GPML), and PPML. However Santos Silva and Tenreyro (2008) in their response, provided justification for the PPML estimator in the context of log linear gravity model, and acknowledged the fact that in some specific situations, the PPML estimator can be outperformed by other estimators.

Martinez-Zarzoso (2013) compares the performance of different estimators via a Monte Carlo simulation exercise and find that although PPML to be less affected by heteroscedasticity compared to FGLS, NLS and GPML, nonetheless, its performance is found to be similar both in terms of bias and standard errors to the performance of the FGLS estimator, particularly for small sample size; with the lowest bias and standard errors found in the GPML in the simulations which has non-zero values in the dependent variable. Further empirical analysis using three different real datasets¹⁰ reveal that the choice of the performance of the model is sensitive to the sample size; for small sample size, FGLS could be perfect way to deal with the heteroscedasticity problem, while the PPML will be appropriate when the sample size is large and there is measurement error in the dependent variable. However, for large sample size, PPML bias is found to decrease in large sample size while FGLS bias is found to remain almost constant. In addition, the PPML standard error falls considerably but it still remains twice the FGLS standard errors. Conclusively, Martinez-Zarzoso (2013) find that the choice of the best estimator is dependent on the specific dataset, and there is no generally best estimator for these three datasets; thus the appropriate estimator for any application is data specific which could be determined using a number of model selection tests.

Martin and Pham (2008) has also challenge Santos Sliver and Tenreyro (2006) findings and posit that although the PPML estimator is less subject to bias resulting from heteroscedasticity problem, however, it is not robust to the joint problems of zero trade flows and heteroscedasticity. Based on this, they conclude that the estimator could be appropriate for other multiplicative models¹¹ which have relatively few zero observations. They proposed that the Eaton and Tamura (1994) threshold *Tobit model* perform better than the PPML and other estimators considered as it recorded the smallest bias in a simulation exercise.

The Monte Carlo simulation done by Santos Sliver and Tenreyro (2006), has also generated some debates. Although the authors find that the PPML is able to deal with zero trade flows, interestingly, their simulation done in order to determine the best performing model were without any zeros, except where the dependent variable was contaminated with measurement errors. This has made some studies to question the performance of the PPML in cases where there are excessive zeros in the dependent variable (c.f. Martinez et. al., 2007; Martinez-Zarzoso, 2013; Martin and Pham, 2008). Martin and Pham (2008) therefore used a data generation process¹² different from that used by Santos Sliver and Tenreyro (2006), which

⁸Santos Sliver and Tenreyro (2006) paper have majorly centred on comparing OLS to the class of GLS, particularly PPML

⁹ Generalized linear models are class of multiplicative models.

¹⁰The 3 dataset consist of about 13%, 15%, 25% of zero trade values.

¹¹For instance the Cobb-Douglas production function, the consumer-demand systems and the Stochastic impact by regression on population, affluence and technology, which is a popular model used in environmental economics.

¹²Santos Silva and Tenreyro (2006) used a data generating process that generates no zero values but only positive values. Martin and Pham adopted similar design to Santos Silva and Tenreyro (2006) Monte Carlo simulation but however modified it by including a threshold trade level that must be exceeded before positive trade levels are observed. Where the chosen threshold generates zero trade frequencies, which is similar to those observed in studies using aggregate trade flows.

include a high proportion of zero values and show PPML to be highly vulnerable to bias in the presence of high percentage of zero values in the dependent variable. Similar result has been found by Martinez-Zarzoso (2013). However these results have been challenged by Santos Silva and Tenreyro (2011).

In response to these studies, Santos Sliver and Tenreyro (2011), argued that both of the simulations done by Martinez-Zarzoso (2013) and Martin and Pham (2008) reveal no information on the performance of the PPML model of constant elasticity model as the data used in their simulation exercises are not generated by a constant elasticity model. Santos Sliver and Tenreyro (2011), however, further investigate the performance of the PPML estimator when the dependent variable has large percentage of zeros and when the data generating process is given by a constant elasticity model (both of which are typical in trade data used in gravity modeling). Similar to their 2006 findings, they also find the PPML estimator to be consistent and generally well-behaved in the presence of high proportion of zeros, and to be more robust to departures from the heteroscedasticity assumption (overdispersion); as its performance is not affected even with the overdispersion in the dependent variable and the presence of excessive zero values.

Among the class of the generalized linear models, the Gamma Pseudo Maximum Likelihood (GPML) technique has also been used in taking care of the zero trade values and associated problem of the logarithm transformation (c.f. Manny and Mullay, 2001). Similar to the log linear model, the GMPL is said to be a more efficient estimator under the assumption that the conditional variance is a function of higher powers of the conditional mean, as it gives more weights to the conditional mean. Santos and Sliver and Tenreyro (2011) found that the GPML is consistent and well behaved under Monte Carlo simulation in the presence of excessive zero values whose data generation process follows the constant elasticity model. However, it is found to have a larger bias than the PPML suggesting that the PPML the best performing estimator (c.f. Santos Sliver and Tenreyro, 2011). In addition, Martinez- Zarzaso (2013) noted that the GPML may also suffer from substantial loss of precision particularly if the variance function is misspecified or if the log-scale residuals have high kurtosis.

Another class of the generalized linear model is the nonlinear least square (NLS) technique, which has also been used in the trade literature (c.f. Frankel and Wei, 1993) or used in comparison with other non-linear estimators (e.g. Santos Silva and Tenreyro 2006; Gomez-Herrera, 2012; Martinez-Zarzaso, 2013). Santos Silva and Tenreyro (2006) however show that although both GPML and NLS can be take care of these two problems, the PPML is still the preferred estimator as the NLS technique assign more weight to noisier observations, which reduces the efficiency of the estimator. This is because while PPML gives the same weights to all observations, and assumes that the conditional variance is proportional to the conditional mean, however, GPLM and NLS give more weights to observations with large mean. This is because the curvature of the conditional mean is more pronounced here, which are also generally observations with large variance, implying nosier observations. In addition, *ibid* noted that the estimator can also be very inefficient because it generally ignores the heteroscedasticity in the data.

Heckman (1979) sample selection model¹³ has also been frequently used in the literature. Noting that the standard practice of excluding zero bilateral trade observations can potentially

¹³ Heckman model is also referred to as sample selection or Tobit II model. The model makes a selection of trading and non-trading country pairs – sample selection.

give rise to sample selection bias, especially if the eliminated zeros are not randomly done, and estimating non-randomly selected sample is a specification error and can potentially bias the results. Heckman, therefore, developed a model that corrects for this sample selection bias which is a two-step statistical approach in which the model is estimated under the normality assumption. The first step of the Heckman model involves estimating an equation (Probit regression) for the probability of exporting at the firm level based on the decisions of the firms and then using it in estimating the volume of trade. Heckman (1979) correction model allows one to correct for selection bias in non-randomly selected samples and has also been frequently used in the gravity model trade literature to correct for problems relation to zero valued trade flows (c.f. Linder and Groot, 2006; Munasib and Roy, 2011). Linder and Groot, (2006) noted that sample selection model uses the information provided by the zero valued trade observations; thus, providing information on the underlying decision process regarding the zero trade flows, while arbitrary truncating and censoring are ad-hoc crude methods and they do not give accurate results compared to the sample selection model. They argued that unlike truncated OLS, without sound theoretical background, the samples election model is theoretically sound and offers an econometrically elegant solution to estimate gravity equation that includes zero trade flows.

However, in a methodological paper, Helpman, Melitz and Rubinstein (2008) (thereafter HMR), noted that the estimation of bilateral trade flows using the gravity equation is not only subjected to sample selection bias (if the non-zero exports do not occur randomly), but that estimates may also be vulnerable to omitted variable bias if the number of exporting firms within an industry (extensive margin of trade) is not accounted for. The idea is that due to trade costs, firms differ in productivity (firm heterogeneity) and only firms with productivity level beyond a threshold end up exporting.

HMR therefore extended Heckman (1979) procedure by controlling for both sample selection bias and firm heterogeneity bias and solve the zero problem by also developing a two-steps estimation procedure which exploits the non-random presence of zero trade flows in the aggregate bilateral trade data. The aim of the HMR two-step procedure is to correct both the sample selection bias resulting from eliminating zero trade flows when estimating the logarithmic form of the gravity equation and the bias caused by unobserved firm heterogeneity which result from omitted variable, which also measures the effect of the number of exporting firms (extensive margin). The first step involves estimating an equation (Probit regression) for the probability of exporting at the firm level based on the decisions of the firms and then using it in estimating the effects on the extensive margin of trade (the decision to export from country i to j). The second step is a gravity equation estimated in its logarithm form and involves using the predicted probabilities obtained in the first step to estimate the effects on the intensive margin of trade (the number of exporting firms from country i to j).

Helpman et al., (2008) posit that the excluded variable must not be correlated with the error term of the second stage equation but must be correlated with trade volume (the dependent variable). In addition, the excluded variable must be influence trade through fixed trade cost and not through variable trade cost because the latter impact on the extent of trade volume, and as such, is not uncorrelated with the second stage equation. However, Burger et al., (2009) noted that one important drawback of the Heckman (1979) and Helpman et al. (2008) models is that it is difficult to satisfy the exclusion restriction as the instrumental variable is most often difficult to find. Examples of exclusion variables used in the literature are common religion

and common language variables (Helpman et al., 2008); governance indicators of regulatory quality (Shepotylo, 2009); historical frequency of positive trade between country pairs (Linder and de Groot, 2006; Haq et al., 2010 and Bouet et al., 2008). However, both Linder and de Groot (2006) and Haq et al., (2010) include the excluded variable in both equations and impose the normality of the error term in the two equations – an identification condition implying a zero covariance between both equations.

Notwithstanding the aforementioned advantages of the HMR, some limitations have been identified regarding its application. Both the Heckman (1979) and the HMR trade flow equations are usually transformed to the logarithmic form before estimated and might cause biased coefficient (Haworth and Vincent, 1979; Santos Silva and Tenreyro, 2006). In addition, Santos Silva and Tenreyro (2009) and Flam and Nordström (2011) also show that HMR does not control for heteroscedasticity which is usually pervasive in most trade data. For instance, Santos Silva and Tenreyro (2009) show that the assumption of homoscedasticity¹⁴ error term for all country pairs by the HMR results in serious misspecifications as HMR does not control for heteroscedasticity, consequently casting doubts on the validity of inferences drawn from the model. They also pointed out that in contrast to models which can be made robust to the presence of heteroscedasticity, the consistency of the HMR model is only possible under the ‘unrealistic’ homoscedasticity assumption, which they identified as the most important drawback of the model as it is too strong to make it applicable or practicable to trade data in which heteroscedasticity is pervasive. They therefore posit that the presence of heteroscedasticity in the data preclude the estimation of any model that purports to identify the effects of the covariates in the intensive and extensive margins, at least with the current econometric technology (Santos Silva and Tenreyro, 2009).

In sum, as noted in the review, each technique has its pros and cons and the ‘workhorse’ or best performing model for the estimation of the gravity equation still remains unclear as the consensus on a commonly accepted solution has not yet been reached. Therefore, given the pros and cons of each estimator, the determination of the best performing estimator (given our set of data application) remains an empirical issue.

3.2. RELATED LITERATURE

With the increasing role of food safety standards in as a non-tariff trade barrier, several studies have empirically investigated the impact of these standards and or regulations on international trade, and more specifically on agri-food trade using both aggregated and disaggregated data. In most cases, gravity models are typically used in evaluating the empirical role that standards exert on trade flows. As previously identified, the estimated gravity model within the standard-trade literature might show scope for improvement especially in two areas: the econometric estimation technique and the proper specification of the model, especially given the peculiarities of the countries studied.

Early studies on food standard-trade have estimated the standard log linear gravity model using OLS both with the occurrence and non-occurrence of zero trade flows. For instance, study by Otsuki et al. (2001a, b) (which is perhaps the most cited literature) which investigate the impact of a proposed 1998 EU stricter aflatoxin standard on African exports of groundnut products, have applied OLS estimation techniques and took care of zero trade flows data by adding one to them. This method is said to suffer from deliberate measurement error (Winchester, et al., 2012). However, since the publication of this paper, there have been two

¹⁴ The Helpman et al. (2008) model hinges heavily on both the homoscedasticity and normality assumptions to be consistent.

main developments in the gravity modelling. The first is Anderson and van Wincoop (2003) theoretical paper which show that trade costs should be measured as multilateral trade costs in addition to the usual bilateral trade cost employed. The second and most important development is the issue of zero trade records and the proper estimation technique to tackle it and the problem posed by the logarithmic transformation of the gravity model (Santos Sliver and Tenreyro, 2006).

Various estimation techniques that incorporate zero trade record in the empirical analysis were therefore adopted. For instance, studies by Frahan and Vancautereen (2006), Fontagne, Mimouni and Pasteels (2006); went beyond the OLS technique and instead used the censored Tobit model with random effects in order to deal with the zero trade flows. However, the Heckman model were employed by Chevassus-Lozza et al. (2008), Jayasinghe et al. (2009), Vigani et al. (2010), Disdier and Marette (2010) to tackle the selection bias resulting from eliminating the non-random occurring zero trade flows from the trade matrix. Other studies have taken advantages of the availability of panel data and employed either the random or fixed effect model or both (c.f. Vancauteren and Weiserbs, 2005; Disdier et al., 2008; Jonguanish, 2009; Melo et al., 2012; etc) where the model is log linearized, with the zero trade flows truncated or deliberately deleted.

Nonetheless, following Santos Sliver and Tenreyro (2006), studies by Schlueter, Wieck and Heckelee (2009), Gerrais et al. (2011), Disdier and Fontagne, (2010), Wilson and Bray (2010), Shepherd and Wilson (2013), have applied the PPML to investigate the impact of standards on trade flows and to deal specifically with the presence of zero trade flows observations. However, Winchester et al. (2012) used the generalized NBPPML model following their findings that the PPML does not pass the overdispersion test. Similar method were also employed by Drogue and Demaria (2010), Cadot et al. (2010), all of which rely on the NBPPML. Xiong and Behin (2010) however rely on the Helpman et al. (2008) model to deal with the zero trade flows and to eliminate the potential selection bias.

There are also a few studies which compare different estimation techniques in the presence of zero trade flows (c.f. Xiong and Behin, 2010; Drogue and Dramaria, 2010) to determine the best performing estimator. However, these studies compare only few of the estimators and chose the best performing model within these limited models considered. While some make the comparison between specific estimator(s) such as Heckman or Helpman et al. models and Poisson models (e.g. Xiong and Behin, 2010; Drogue and Dramaria, 2010), others like Santos Silva and Tenreyro (2006) made the comparisons between OLS and Poisson (e.g. Gervais et al., 2011; Shepherd and Wilson, 2010) without considering other possible estimators. Among the linear estimators, most of these studies only consider the PPML, few considered the ZIPML and the ZBPPML (Xiong and Behin, 2010; Drogue and Dramaria, 2010), while none have considered other members of the Poisson class such as the Gamma PML and NLS.

However, as noted by Martinez-Zarzaso (2013), the choice of the best performing model should not be aprior but rather should be based on large number of robust and specification checks and tests. Given this, our analysis would be wider in scope and more encompassing as we will include a wide coverage of estimation techniques and not a subset of techniques as is common practice in the literature, in order to objectively identify the best performing technique. As zero trade usually occur among small or poor countries (Martinez-Zarzaso, 2013), therefore, our focus will be on African countries, majority of which are predominantly poor and the small country assumption is also applicable to them, thus making our dataset to be more appropriate in the test of the most appropriate estimation technique(s). Our application

will be to a unique dataset on standards – the Perinorm standard database- which to our knowledge has not been investigated before to determine the trade effect of standards on African agricultural exports.

4.0. METHODOLOGY

This section presents the model specifications of the various techniques of estimating the gravity model and also describes the data.

4.1 Model Specification and Estimation Techniques

In general, in line with the various estimation techniques previously discussed, the volume of bilateral trade flow between countries i and j in year t can be represented in either the multiplicative or logarithmic forms. For the sake of comparison and completeness, we adopt the Bergstrand (1989) equation as our preferred theoretical model. First, it is widely accepted in the literature; second, it ensures the modelling of multilateral trade resistance which if omitted can bias the estimated gravity coefficients (c.f. Baldwin and Taglioni, 2006; Fenstra 2006, etc).

4.1.1 Log-Linear Models

We begin with the following multiplicative gravity equation:

$$y_{ijt} = \beta_0 GDP_{it}^{\beta_1} GDP_{jt}^{\beta_2} POP_{it}^{\beta_3} POP_{jt}^{\beta_4} S_{jt}^{\beta_5} D_{ij}^{\beta_6} lang_{ij}^{\beta_7} Col_{ij}^{\beta_8} RTA_{ij}^{\beta_9} Landl_{ij}^{\beta_{10}} \varepsilon_{ijt} \quad (1)$$

Taking the natural logarithm of both sides of equation (1), yields a log linear gravity model given as:

$$\ln y_{ijt} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP_{jt} + \beta_3 \ln POP_{it} + \beta_4 \ln POP_{jt} + \beta_5 \ln S_{jt} + \beta_6 \ln D_{ij} + \beta_7 \ln lang_{ij} + \beta_8 \ln Col_{ij} + \beta_9 \ln RTA_{ij} + \beta_{10} \ln Landl_{ij} + \varepsilon_{ijt} \quad (2)$$

Where \ln denotes the natural logarithms of the variables; i and j are exporter and importer subscripts respectively while t denotes time period; y_{ijt} is exports value from country i to country j in time t in current US \$; GDP_{it} and GDP_{jt} are respectively is the gross domestic products of countries i and j in time t in current PPP US \$; whose coefficients are expected to be positive; POP_{it} and POP_{jt} are the population in countries i and j in time per thousand people. GDP and population proxy for the supply and demand capacities of these trading countries. D_{ij} is the geographical distance between the major cities of countries i and j ; $Border_{ij}$ is a dummy that takes the value of 1 when countries i and j share a border, zero otherwise; $lang_{ij}$ is a dummy that take the value of 1 when countries i and j speak the same official language, zero otherwise; Col_{ij} is a dummy variable that takes the value of 1 when countries i had colonized country j in the past, zero otherwise; $Llock_{ij}$ takes the value of 1 when at least one of the country-pair is a landlocked countries, zero otherwise. RTA_{ij} takes the value of 1 when trading countries belong to similar trade agreement, zero otherwise. Finally, ε_{ijt} is the two-way error component term of the model, $\varepsilon_{ijt} = \nu_i + \gamma_t + \mu_{ijt}$; ν_i is the unobserved individual effects; γ_t unobserved time effect; and μ_{ijt} is the remaining part of the stochastic disturbance term. Specifically, ν_i captured the country specific unobservable effects – the

exporter and importer fixed effects δ_i and δ_j respectively; thus, δ_i and δ_j are the exporter and importers fixed effect – the multilateral resistant term while γ_t is the time effect, all of which correct for the biases from estimating panel data (Baldwin and Taglioni, 2006).

Apriori, we expect β_1 and β_3 to be positive as high level of income and population in the exporting country denotes a high level of production ceteris paribus, which increases the exports goods; the coefficients on β_2 and β_4 are also expected to be positive as high income level in importing countries stimulates higher imports. The distance coefficient is however expected to be negative as it is a proxy of all trade cost. The coefficients on lang, Col, Llock and RTA are all expected to be positive.

Equation (2) is generally estimated by pooled OLS and other estimators such as fixed effect and random effect estimators, Tobit, Heckman and Helpman models. Where the log linear equation is consistent when the conditional variance $V[y_i | x]$ is proportional to the square of the mean $E[y_i | x]$, (that is $V[y_{ijt} | x] \propto E[y_{ijt} | x]^2$)

Pooled regression model

The OLS estimation of equation (2) is specified as either as censored OLS in which case, we add a constant ‘c’ to replace the entire zero trade observation or by using the truncated OLS where all zero records are deleted. Here, the model assumes the error term to be linearly and independently distributed with zero mean and constant variance $\varepsilon \sim N(0, \sigma^2)$.

Fixed effects model

An alternative way to estimate equation (2) is to control for unobserved heterogeneity using panel data estimators such as the fixed effects technique. Assuming the variables are correlated with the unobserved heterogeneity, the fixed effects estimator becomes:

$$\ln y_{ijt} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP_{jt} + \beta_3 P_{it} + \beta_4 P_{jt} + \beta_5 \ln S_{it} + \beta_6 RTA + \varepsilon_{ijt} \quad (3)$$

Where ε_{ijt} is the two-way error component model $\varepsilon_{ijt} = \nu_i + \gamma_t + \mu_{ijt}$; ν_i is the unobserved individual effects which is represented or captured by country specific unobservable effects – the exporter and importer fixed effects δ_i and δ_j respectively; γ_t unobserved time effect; and μ_{ijt} is the remaining part of the stochastic disturbance term. Both ν_i and γ_t are assumed to be fixed parameters to be estimated while μ_{ijt} is assumed to be *IID* $(0, \sigma_\mu^2)$. Equation (3) assumes that the explanatory variables and the unobserved heterogeneity are correlated: $E(\nu_i | x_{ijt}) \neq 0$ and $E(\gamma_t | x_{ijt}) \neq 0$ that the explanatory variables are independent of the residual error term μ_{ijt} for all i, j , and t - $E(x_{ijt} | \mu_{ijt}) = 0$; where x_{ijt} is defined as the explanatory variables of the gravity equation in (3) above. All other variables remained as earlier defined. All time invariant explanatory variables are perfectly collinear with the fixed effects and are dropped from the model.

Random effects model

Alternatively, equation (2) can be estimated using the FGLS estimator which on the contrary assumes orthogonally between the explanatory variable and the unobserved heterogeneity (Baltagi, 2008). The random effects model is specified as equation (2) with the difference that the explanatory variables (x_{ijt}) now contains both time invariant and time varying explanatory variables; and $\nu_i \sim IID(0, \sigma_\nu^2)$, $\gamma_t \sim IID(0, \sigma_\gamma^2)$, and $\mu_{ijt} \sim IID(0, \sigma_\mu^2)$; and x_{ijt} is independent of the unobserved heterogeneity ν_i and γ_t as well as the remainder of the error term μ_{ijt} for all i and t - that is, $E(x_{ijt} | \nu_i, \gamma_t, \mu_{ijt}) = 0$

4.1.2 Multiplicative Models' Estimators – The Generalized linear models (GLM)

The generalized linear models estimate the constant elasticity gravity model in its multiplicative form as:

$$y_{ijt} = \exp(x_{ijt} \beta) \varepsilon_{ijt} \quad \dots\dots\dots (4)$$

Where $E(\varepsilon_i | x) = 1$; x_{ijt} are the explanatory variables of the gravity equation earlier defined in equation (1) above; β is the parameters and ε_{ijt} is the composite error term which contains the importer and exporter fixed effects, time effects and the remainder of the error term.

The Poisson Pseudo Maximum Likelihood (PPML) Estimator

The PPML estimates β by solving the following first-order conditions:

$$\sum_{i=1}^n [y_{ijt} - \exp(x_{ijt} \beta)] x_{ijt} = 0 \quad \dots\dots\dots (5)$$

Equation (10) is the PPML estimator, which is consistent¹⁵ under the estimator's equidispersion¹⁶ assumption that the conditional mean $E[y_{ijt} | x]$ given as $\exp(x_{ijt} \beta)$ is equal to the conditional variance $V[y_{ijt} | x]$ - this is implied by equation (11) which imposes restrictions on the conditional moments of the dependent variable.

$$E[y_{ijt} | x] = \exp(x_{ijt} \beta) \propto V[y_{ijt} | x] \quad \dots\dots\dots (6)$$

However, the equidispersion assumption is unlikely to hold (Santos Sliver and Tenreyro, 2006; Martinez-Zarzaso, 2013) as the estimator does not fully account for the presence of heteroscedasticity in the model. In other words, the estimator does not fully take account of the presence of unobserved heterogeneity caused by the unobserved trade costs, thus making the conditional variance to be greater than the conditional mean¹⁷. Thus, inferences are based on the Eicker-White robust covariance matrix estimator (Eicker, 1963; White, 1980).

Negative Binomial Poisson Maximum Likelihood (NBPML) Estimator

¹⁵ To obtain consistent estimates, while the trade flow variable is assumed to follow a Poisson distribution, however, the data need not follow a Poisson distribution, and the independent variable needs not be an integer (Gourieroux, Monfort, and Trognon, 1984).

¹⁶ PPML gives the same weights to all observations, such that all the observations have the same information on the parameters because the additional information about the curvature of the mean which comes from observations with large mean is offset by their large variance (Santos Sliva and Tenreyro, 2006).

¹⁷ Although the PPML specification hinges on the assumption of equidispersion of the dependent variable, however, SST 2006 show that the PPML is still well-behaved and consistent even with departure from this assumption.

Since the equidispersion assumption does not always holds for the Poisson model, the Negative Binomial (NB) model, a modified Poisson model is alternatively employed to deal appropriately with the occurrence of overdispersion in the dependent variables (c.f. Burger et al., 2009). Following Winkelmann (2008), the negative binomial probability distribution function for y is given as:

$$\Pr[y_{ijt}] = \frac{\Gamma(\alpha + y_{ijt})}{\Gamma(\alpha)\Gamma(y_{ijt} + 1)} \left(\frac{\alpha}{\alpha + \exp(x_{ijt}\beta)} \right)^\alpha \left(\frac{\exp(x_{ijt}\beta)}{\alpha + \exp(x_{ijt}\beta)} \right)^{y_{ijt}} \dots\dots\dots(9)$$

Where Γ is the gamma function, α is the dispersion term which allows the conditional variance to exceed the conditional mean and also determines the degree of variance dispersion (Verbeek, 2004; Cameroon and Trivedi, 1986). The larger α is, the larger the degree of overdispersion in the dependent variable. A likelihood ratio test on α can be used to test if the NBPML is more appropriate model compare to the PPML (Cameroon and Trivedi, 1986; Winkelmann, 2008).

In NBPML model, the expected value is given as that of the PPML, however, the variance is specified to include the mean $\exp(x_{ijt}\beta)$ and an unobserved heterogeneity given as a dispersion parameter α ¹⁸ which allows unobserved heterogeneity to be incorporated into the model. In addition, the dispersion parameter is allowed to take on other values than 1, thereby explicitly taking care of overdispersion.

4.2. Estimation Strategy

Equation (2) is the general log-linear model and can be estimated using OLS; fixed effects model, FGLS, Heckman and Helpman et al. models, Tobit, etc. Equations (9) is the multiplicative model which can be estimated using the PPML, the negative binomial and other models such as Gamma PML, inflated family such as the NB(PML), ZINB(PML), and ZIP etc with the preferred estimator depending on the assumptions about the characteristics or functional form of the conditional variance of the dependent variable.

Our approach is to investigate how zero values in the dependent variable affect the performance of our estimators. In particular, we are also interested in investigating whether the homoscedasticity assumption holds for each estimator and their performances in the presence of heteroscedasticity. We investigate the performance in of zero trade flows containing about 70% zero trade observations . We are interested in ascertaining whether the patterns of heteroscedasticity assumed by the various estimators are acceptable.

Following Santos Silva and Tenreiro (2006) and Martinez-Zarzaso (2013), we proceed by assessing and comparing the performances of the selected estimators. Comparison of the performances of the various estimation techniques would be based on the mean square error (MSE) also known as standard error, and the bias of the estimate and the absolute error loss which is a class of the expected error loss (which gives the risk of the estimator). As identified

¹⁸This dispersion parameter serves as a formal test of overdispersion in the dependent variable.

by Martinez-Zarzaso (2013), its main advantage over the bias is that over and under estimations cannot be cancelled out unlike the case of the bias¹⁹.

These performance criteria are given as:

$$\text{Bias} = (\beta, \hat{\beta}) = \beta - \hat{\beta} \dots\dots\dots(10)$$

$$\text{Absolute error loss} = L(\beta, \hat{\beta}) = |\beta - \hat{\beta}| \dots\dots\dots(11)$$

$$\text{The square error loss} = L(\beta, \hat{\beta}) = (\beta - \hat{\beta})^2 \dots\dots\dots(12)$$

$$\text{Mean square error} = E(\beta - \hat{\beta})^2 \text{ or } Var(\hat{\beta}) + (\beta - \hat{\beta})^2 \dots\dots\dots(13)$$

In addition, graphical goodness of fit criteria would also be employed. These are the kernel density of each estimator to compare the bias and variance of the distribution of the predicted values of each estimator; the dispersions of the results and the predicted over the real value of exports are all plotted to give graphical view of the performance.

Performances among the GLM estimators are checked using the Akaike information criterion (AIC) and the Bayesian information criterion (BIC). AIC and BIC are also used to check the performance among the linear model.

The equidispersion assumption would be tested using the Gauss-Newton regression (c.f. Davidson and MacKinnon, 1993) while the overdispersion assumption (choice between PPML and NB models) is determined using the likelihood test, Langrangian Multiplier test and Young test. To test the Poisson restriction, the likelihood ratio and Wald test are employed to affirm whether the ZIP is more appropriate model compare to the ZIPML. Likewise, the Vuong test (Vuong, 1989) is employed to test if the Zero Inflated models are more appropriate than the non-Zero Inflated models in the presence of excess zeros (see Winkelmann, 2008).

Finally, Park-type test (Park, 1966) is used to check for the adequacy of the log linear model versus the GLM models as well as to determine the pattern of heteroscedasticity assumed by the estimators (are accepted). In addition, the Ramsey Reset test (Ramsey, 1969) is also used to check for the adequacy and misspecification of all the estimators.

5.0 RESULTS AND DISCUSSION

Table1 presents the results of the theoretically justified gravity model for both the least square estimators and the generalised linear models. The dependent variable for the former models is the logarithm of exports and for the latter, it is in levels.

<Table 1 about here>

For all models, the coefficients on the income elasticities of exporters' GDP are far below the theoretical value of 1. However, there have been justifications for the coefficients on exporter and importers' elasticities of income to fall below or above one in the literature. Furthermore,

¹⁹Martinez-Zarzaso (2013) noted that although most studies usually consider unbiasedness or small bias as the most desirable property of an estimator, and therefore the major criterion of comparing estimators. However, unbiased is not necessary also good estimator as over and under estimations may cancel out, leading to misleading result.

the coefficients are insignificant when the gravity equation is estimated by OLS, Truncated, PPML and NBML.

In the same vein, the coefficients on income elasticities for the importing countries also show similar trend, with the exception that the coefficient is closer to the theoretical value of 1 when PPML model is used. The coefficient is also statistically significant for only the PPML and FGLS models while the coefficients on the other estimators negate our aprior expectation.

Regarding the exporters' population, all the model predicts negative and statistically significant effect on exports in line with our apriori expectations, with the exception of Tobit model which produce a negative albeit insignificant effect. Furthermore, the Tobt and NBPML estimates predicts positive and statistically significant effects of importers' population size on exports, confirming our aprior expectation. In contrast, all the other remaining estimators produce insignificant elasticities effect.

Concerning fish standards, all models point to negative effects on exports. However, OLS, Truncated, FGLS, PPML and NPML produce a significant effects on exports while OLS+1, Tobit, Fixed effects and Random effects models all predicts an insignificant effects of EU standards on fish exports.

With respect to geographical distance, as expected, the estimated elasticity is significant and negative for OLS, OLS+1, Truncated, FGLS, Random effects, and NBPML models. However, PPML, Fixed effects, and Tobit model predict no significant effects on trade.

With respect to the rest of the gravity variables, all models predict an insignificant trade effect of sharing a common language on exports. The common border variable is however statistically significant when OLS, OLS+1, Truncated, FGLS and NBPML models are used and the standard error is significantly lower for FGLS estimates, rendering it more precise. Instead, the Tobit, Fixed effects, Random effects and PPML models predict no significant border effect on exports.

Contrary to our expectations, regional trade agreements between country-pairs does not have any effect on trade for all models except for the FGLS and NBPML models where it has a positive and large significant effect on fish exports. With respect to landlocked variable, only the Tobit and PPML models predict a significant and positive effect, whereas all the other remaining models produce insignificant trade effects when the landlocked variable is considered. Distinctively, NBPML produce a positive and significant positive trade effects for landlocked countries compared to non-landlocked countries, which is not indicative of a correct specification.

In general, from Table 1, the differences in the techniques is mostly seen in the magnitude of the standard errors and coefficient predicted and in seldom cases, in the signs of the parameters

of the gravity variables. However, the main differences between them lies in the standard error, the measure of precision. Table 2 summarizes the top 3 estimators with the lowest standard error. We could see that OLS+1, FGLS, Tobit, NBPML and PPML in rare case exhibit the least standard errors depending on the variable considered, however, OLS+1 in which case, one is added to the dependent variable is said to be theoretically inconsistent.

<Table 2 here>

Robust Checks

In other to better compare the different estimation techniques, we employ several goodness of fit criteria discussed below.

Our approach is to investigate how zero values in the dependent variable affect the performance of our estimators. In particular, we are also interested in if the homoscedasticity assumption holds for each estimator and their performances in the presence of heteroscedasticity. We investigate the performance of zero trade flows containing about 70% zero trade observations. We are interested in if the patterns of heteroskedasticity assumed by the various estimators are acceptable.

As could be seen from the previous chapter, the general form of the variance function of the GLM and log-linear model is given as $v(y | x) = k(\mu(y\beta))^{\lambda}$ (14)

In equation 14, λ is non-negative and finite and its value determines the different GLM²⁰ and log-linear model. For instance, for values of $\lambda_1 = 1$, we obtain the NLS estimator; when $\lambda_1 = 2$, we obtain the PPML; when $\lambda_1 = 1$, we obtain the GPML and log-linear estimators.

Given the above variance function, Manning and, Mullaby, (2001) suggest that the choice of the appropriate estimator could be based on a Park-type regression. To determine the pattern of heteroscedasticity assumed by the estimators, we therefore rely on a Park-type test (Park, 1966) which checks for the adequacy of the log linear model and the GLM models. To check the adequacy of the log-linear mode, the test consists of estimating the following equation which can be directly derived from equation (14). This is specified as:

$$\ln(y_i - \hat{y}_i)^2 = \ln(\lambda_0) + \lambda_1 \ln \hat{y}_i + \mu_i \quad (15)$$

²⁰ Because the negative binomial models and the zero inflated models have one additional parameter (alpha), the choice of the appropriate estimator is not the park test but rather the wald test, the likelihood-ratio test statistic or the Young test are employed to test the Poisson restrictions (see Winkelmann, 2008)

Based on a nonrobust covariance estimator, the null hypothesis is that $H_0: \lambda_1 = 2$ (that the model is a log-linear one) is tested against the alternative that it is not. However, because logarithmic transformation of equation (15) is only valid under restricted conditions of the conditional distribution of (Santos Siliva and Tenreyro, 2006 and Martinez-Zarzaso, 2013, we also estimate the modified version of the Park regression as a more robust alternative. According to Manning and Mullahy, 2001; Deb, Manning and Norton (2008), a more robust alternative is to estimate λ_1 from

$$(y_i - \hat{y}_i)^2 = \lambda_0 (\hat{y}_i)^{\lambda_1} + \eta_i \dots\dots\dots(16)$$

using the appropriate GML estimator based on the Eicker-White robust covariance matrix estimator. Here, the dependent variable now is $(y_i - \hat{y}_i)^2$ while the regressors are $x\beta$ from each of the GLM estimators of y on x . Manning and Mullahy (2001) and Deb, Manning and Norton (2008) ‘straightforward approach’ as that gives a confidence interval for λ_1 . The null hypothesis is that H_0 : i.e. is equal to is tested against the alternative that it is not. The hypothesis is accepted if the appropriate confidence interval for λ_1 contains 1.

The results of the Park test is presented in Table 3. We report the p-values of the test which checks whether the pattern of heteroscedasticity assumed by each models is appropriate. Among the estimators, only the FGLS, Random effects and NBPML models passed the test which suggests that the other models are inadequate given the dataset considered. For these three aforementioned models, the estimated coefficients on insignificantly different from zero at the 5% conventional significance level.

<Table 3 about here>

The performance of the log linear estimators and GLM are also tested using the Akaike information criterion (AIC) and the Bayesian information criterion (BIC). However, the results for the log linear and GLM estimators are directly incomparable due to the differences in the number of observations. The results are presented at the bottom of Table 1. Among the log linear models, the Fixed effects model, Truncated and Tobit models presented the lowest AIC and BIC results while OLS+1 model presents the highest AIC and BIC criteria, once again indicating its inadequacy. However, for the GLM estimators, NBPML model presents the lowest AIC and BIC results.

To test the poisson restriction, the likelihood ratio is employed to affirm if the PPML is more appropriate model compare to the ZBPML (see Winkelmann, 2008). The proportionality assumption is checked by using the likelihood ratio test reported by the NBPML estimator. This is shown in the last row of Table 1. The likelihood ratio test is the test of the over-dispersion parameter (alpha). Here, the result shows that alpha is statistically significantly different from zero, thus reinforcing that the Poisson distribution is not appropriate.

We use a (heteroscedasticity-robust) Ramsey Reset Test (Ramsey, 1969) to check the adequacy of all the estimated models. In essence, it checks if the conditional expectations are correctly specified. This is performed by checking the significance the additionally constructed regressor where $\hat{\beta}$ is the vector of all estimated parameters. The null hypothesis is that the coefficient on the test variable is 0 or insignificant. The p-values of the reset test is provided at the bottom of Table 1. The test is not statistically significant for all estimators both log linear and GLM, signifying that none of the estimators considered passed the functional form test. The results obtained could be due to the omission of relevant variables such as tariff which has been omitted in our model due to the fact that Africa enjoys tariff concession on its fish exports to the EU.

Three performance criteria are also used in assessing and accessing the performances of the selected estimators; these are the mean square error (MSE) also known as standard error, and the bias of the estimate and the absolute error loss (AEL). The results of these 3 goodness of fit criteria are presented in Table 4. Our findings indicate that all the estimators present a bias of different magnitudes; Fixed effects and OLS+1 estimators exhibit the lowest bias while PPML exhibits the strongest bias.

Concerning the MSE criteria, OLS+1 estimator shows the least variance followed by OLS and FGLS; whereas, PPML and Fixed effects estimators produce the worse outcome. The last column of Table 4 presents the absolute error loss results. Again, OLS+1 estimator shows the least error loss followed by OLS and Truncated OLS while Fixed effects and PPML models perform worse among the log linear and GLM estimators.

<Table 4 about here>

These results are not unexpected: noticeably, for all 3 criteria the distribution of PPML and NBPML estimators differs significantly from all the others in its kurtosis and skewness. This is shown from the kernel density of the estimation which we employed to give a visual evidence of the bias and the variance of the estimators. Firstly, while the other estimators are normally distributed and slightly skewed to the left, the GLM estimators are not normally distributed, but instead are badly skewed to the right and exhibits large biases. Secondly, the GLM estimators show very high kurtosis and their distribution appears to be platykurtic (exhibiting very high variance) and high bias while the distribution of the log linear models rather show lower kurtosis and lower variance, and lower bias. Therefore, the prediction of the GLM technique is rather very poor for our kind of dataset which is characterized by very low trade values and many zeros. Overall, for the linear models, These are reported in Figures 1 and 2 in the appendix

Finally, we plot the fitted value over the predicted in a graph to better show the fit of the distribution, which we present in Figures 3 to 11 in the appendix. The plots of the individual graphs for each estimator also confirm the above results of the goodness of fit criteria. The plot shows the distribution of log linear estimators to be closest to the real distribution in contrast to the GLM model.

6.0 CONCLUSION

The issues of zero trade observations and the validity of the log linear transformation of the gravity equation in the presence of heteroscedasticity have generated a number of claims and controversies in the literature. Various estimation techniques that incorporate zero trade record in the empirical analysis were therefore adopted. This paper seeks to validate the claims in the literature concerning the best performing estimator using African dataset on fish exports to the EU consisting of over 70% zero trade flows. We provide an in-depth review of methods that have been employed in solving these problems. Our survey of studies at the forefront of the current debate show that each estimator is not without its pros and cons.

As an empirical analysis, we adopted the Bergrand (1989) specification of the gravity equation. From our analysis, it is clearly difficult to pinpoint a particular estimation technique as the best: as it depends on the dataset considered. Given our dataset and the gravity equation specified, our results shows that there is no one general best performing model, although most of the linear estimators outperform the GLM estimators in many of the robust checks performed. Previous empirical studies have also shown that there are now several theoretically-consistent estimation methods. These are PPML by Santos Silva and Tenreiro, (2006); Heckman model by Gomez-Herrera(2013); FGLS by Martinez-Zarzaso (2013); Helpman model by Helpman et al,(2008); Tobit model by Martin and Pham,(2008) etc. From these studies, one can deduce that it is difficult for a sole reliance on any one method, thus, following Head and Mayer, (2013), we instead advocate an encompassing toolkit approach of the methods. A particular estimator may be preferred for certain types of dataset or and research questions, but more importantly, the estimators should be used in concert so as to establish robustness. Thus, the gravity model (estimators) should be used as a cookbook and toolkit in explaining bilateral trade (Head and Mayer, 2013).

In conclusion, in order to objectively identify the most appropriate estimation technique(s), the choice of the best performing model should not be aprior but rather should be based on large number of robust and specification checks and tests (see also Martinez-Zarzaso, 2013; Head and Mayer, 2013). It might depend largely on one's dataset and probably on the research questions of the study.

Table 1: Results from the Various Estimators

	OLS lfishes b/se	OLS (1+X) lfishes+1 b/se	Trun OLS lfishes b/se	Tobit lfishes b/se	FGLS lfishes b/se	Fixed lfishes b/se	Random lfishes b/se	PPML fishes b/se	NBPML fishes b/se
Log of Exporter GDP	0.289	0.134*	0.240	0.322***	0.230**	0.313*	0.314*	0.196	0.062
	0.157	0.065	0.160	0.092	0.086	0.157	0.152	0.180	0.102
Log of Importer GDP	0.256	-0.146	0.529*	-0.030	0.391**	0.164	0.179	0.839***	0.146
	0.264	0.104	0.267	0.127	0.128	0.262	0.256	0.246	0.166
Log of Exporter Population	-2.838***	-0.885*	-2.773***	-0.145	-2.358***	-2.614**	-2.643***	-1.525*	-1.482***
	0.800	0.418	0.837	0.106	0.402	0.813	0.801	0.610	0.446
Log of Importer Population	0.783	1.146	-2.895	0.664***	1.955	2.351	2.140	-2.700	3.316***
	2.422	0.747	2.462	0.147	1.105	2.635	2.575	2.046	1.268
Fish Standard	-1.957*	-0.429	-2.978***	0.912	-1.380**	-1.439	-1.478	-1.624*	-0.850*
	0.850	0.366	0.824	0.525	0.431	0.831	0.819	0.682	0.474
Log of Distance	-1.699**	-1.576***	-1.668**	-0.086	-1.005***	2.503	-1.850***	-1.324	-1.226***
	0.524	0.470	0.525	0.246	0.167	2.057	0.476	1.450	0.340
Common Language	-0.072	0.047	0.007	0.465	-0.076	-0.322	-0.033	-0.517	0.147
	0.265	0.202	0.288	0.288	0.118	0.501	0.250	0.576	0.196
Colony	1.052***	1.246***	1.038***	-0.303	0.538***	-0.272	0.383	0.438	0.420*
	0.288	0.356	0.308	0.369	0.113	0.509	0.278	0.670	0.224
Landlocked	-1.093	0.284	-8.110	-1.804***	0.895		1.196	-9.052*	6.263***
	4.689	1.539	4.780	0.197	2.124		4.993	3.921	2.406
RTA	0.046	-0.159	0.262	0.200	0.146*	0.037	0.028	0.101	0.136**
	0.165	0.109	0.149	0.141	0.061	0.159	0.157	0.102	0.064
Constant	35.897	8.995	94.038*	-1 0.158**	-0.076	-24.950	10.080	58.815	-31.106
	39.721	12.904	39.507	3.289	18.127	43.628	41.641	34.295	20.954
Observations	6586	6586	6586	6586	6586	6586	6586	18969	18969
AIC	28432.4	81503.14	24226.95	24762.91	28436.4	23204.22		1.16e+07	101811.3
BIC	29009.78	82186.17	24804.89	24851.22	29027.36	23265.35		1.16e+07	102510
LR Test									0.000
Ramsey	0.000	0.000	0.000	0.000	0.000	0.0001	0.000	0.000	0.000

Note: the dependent variable is the logarithm of exports for all models except for the Poisson and Negative Binomial regression whose dependent variable are exports in levels. All models include exporter and importer fixed effects except Tobit model which could not be estimated with them due to the incidental parameter problem. * p<0.10; ** p<0.05; *** p<0.01.

Table 2: Estimators with the Lowest Standard Errors

Variable	(1)	(2)	(3)
Log of Exporter GDP	OLS+1	FGLS	Tobit
Log of Importer GDP	OLS+1	Tobit	FGLS
Log of Exporter Population	Tobit	FGLS	OLS+1
Log of Importer Population	OLS+1	Tobit	FGLS
Fish Standard	OLS+1	FGLS	NBPML
Log of Distance	FGLS	Tobit	NBPML
Common Language	FGLS	NBPML	OLS+1
Colony	FGLS	NBPML	Random Effects
Landlocked	Tobit	OLS+1	PPML
RTA	Tobit	OLS+1	FGLS
.			

Table 3: Testing for the Pattern of Heteroscedasticity

Estimators	Park Test
	(P-value)
OLS	0.000***
OLS+1	0.000***
Trun OLS	0.000***
Tobit	0.000***
FGLS	0.064*
FE	0.000***
RE	0.827
PPML ^o	-
NBPML	0.951

^oNote: A modified park test could not be estimated for PPML because the resulting model failed to converge.

Table 4: Goodness of Fit Criterion

Estimators	Bias	MSE	AEL
OLS	-1.23E-009	4.2777	1.6080
OLS+1	-5.00E-010	4.2556	1
Trun OLS	-0.0373	4.4811	1.622
Tobit	1.0669	10.4985	2.6884
FGLS	-1.18E-009	4.2778	2.0628
Fixed Effects	-4.60E-009	37.1390	4.9596
Random Effects	0.2310	4.5384	1.6814
PPML	2446.462	2.92E+008	2448.6010
NBPML	2451.164	2.91E+008	2451.165

Figure 1: Kernel Densities of Linear Estimators

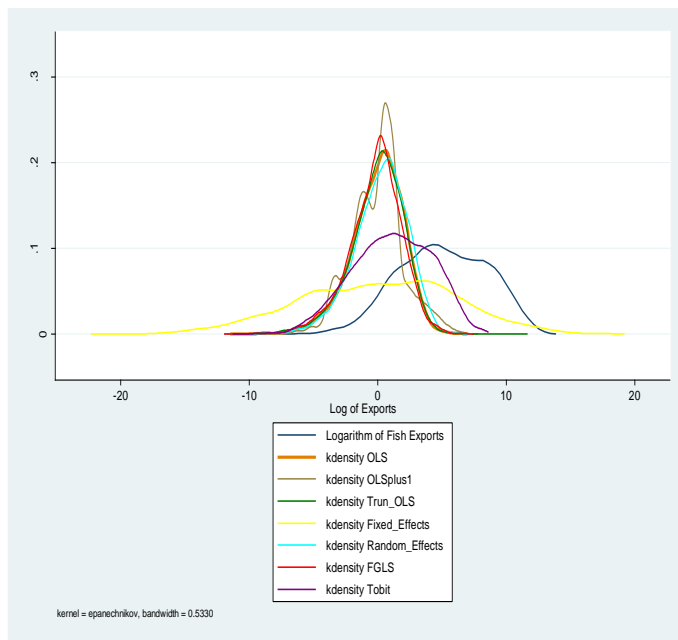


Figure 2: Kernel Density of PPML

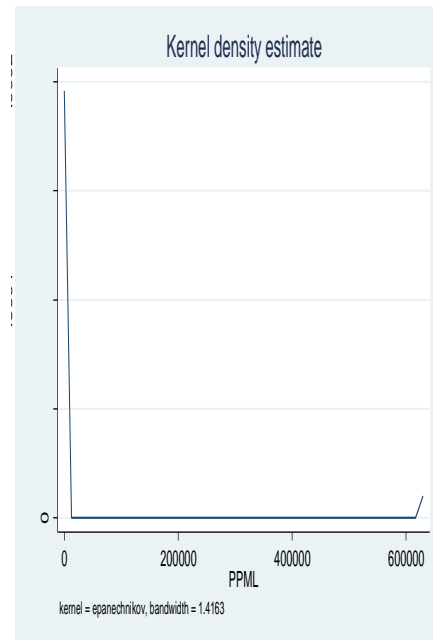


Figure 3: OLS Estimator

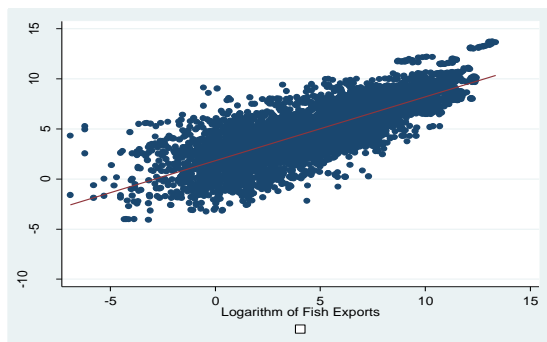


Figure 4: OLS +1 Estimator

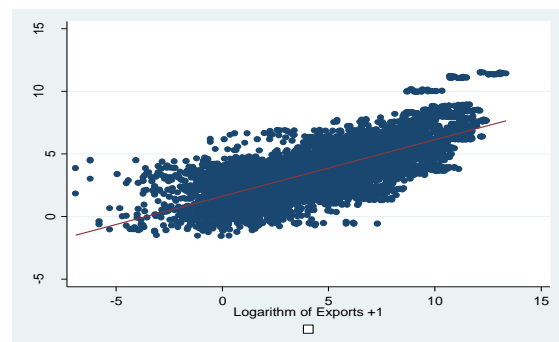


Figure 5: Random Effects Estimator

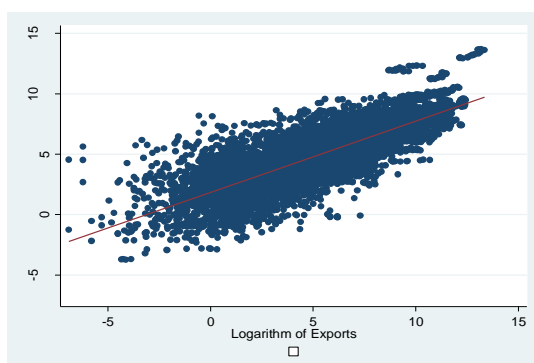


Figure 6: Fixed Effects Estimator

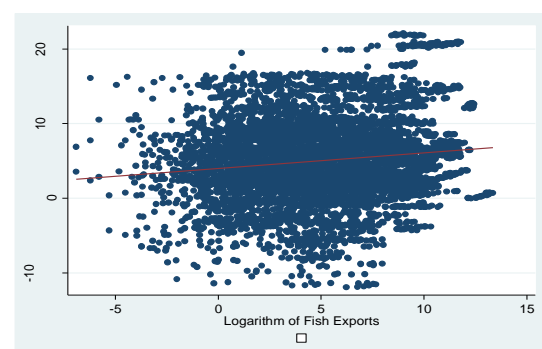


Figure 7: Tobit Estimator

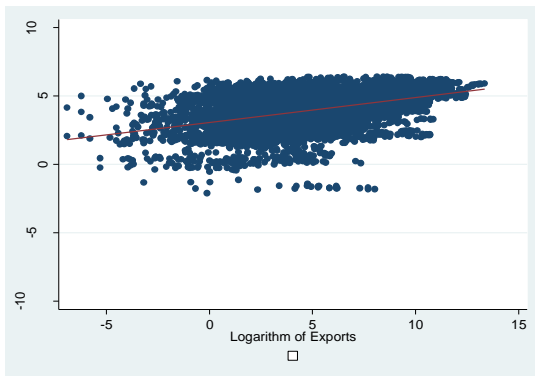


Figure 8: Feasible Generalized Least Square Estimator

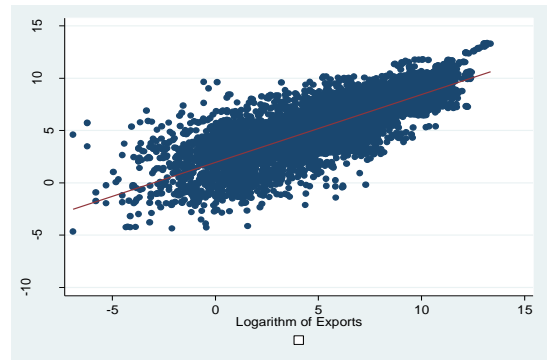


Figure 9: PPML Estimator

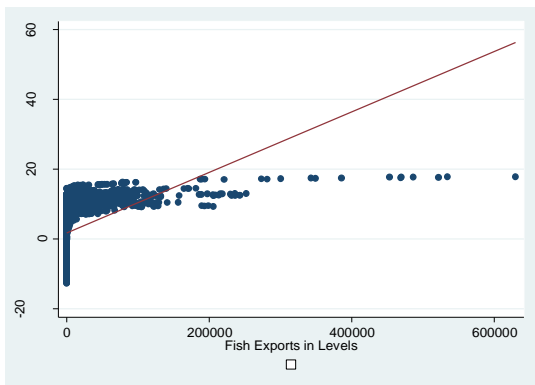


Figure 10: NBPML Estimator

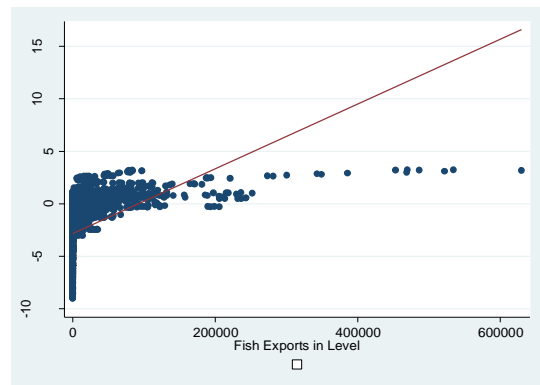
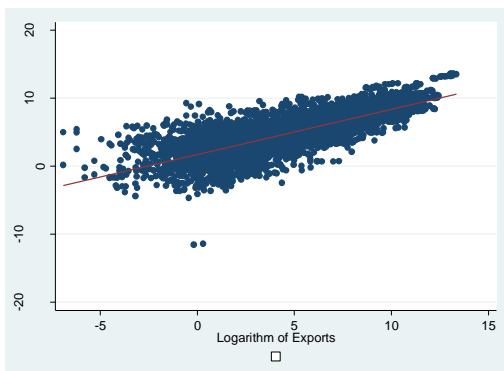


Figure 11: Truncated Regression Estimator



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