2012

Three essays on non-tariff measures and the gravity equation approach to trade

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Three essays on non-tariff measures and the gravity equation approach to trade

by

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A dissertation submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Economics

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Ames, Iowa

2012

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ABSTRACT

Following multilateral and regional trade agreements, import tariffs on agricultural and food products have been declining globally. Meanwhile, the proliferation of non-tariff measures (NTMs), including Sanitary and Phytosanitary (SPS) measures and Technical Barriers to Trade (TBTs), has been triggering trade concerns and protracted trade disputes, and efforts to harmonize these measures. Most standard-like NTMs allegedly protect human and animal health, and the environment from foreign threats. The rising public awareness of food safety and/or consumption externalities drives the emergence of these measures. Protectionist motives may also ride on this emergence and lead to unnecessary impediments in international trade. Delineating the complex impacts of these standard-like NTMs on trade and welfare is central to inform market participation by various stake-holders, as well as for sound policy design. My dissertation contributes new knowledge to the understanding of the impacts of NTMs in agricultural and food markets. Further, the three essays in the dissertation have an additional common thread. They focus on the gravity equation approach to trade, the workhorse used in the analysis and quantification of the effects of NTMs and other trade costs.

The first essay examines whether the harmonization and tightening of European Union (EU) regulations of aflatoxin maximum residue limits (MRLs) have impeded African groundnut exports. Using the state-of-the-art gravity equation approach, I revisit early ex-ante findings of a World Bank investigation predicting a dire adverse effect of the then forthcoming harmonization and tightening on African exports of groundnuts. I find that these African exports are constrained by their own domestic supply limitations, but that the actual harmonization and tightening of EU’s aflatoxin MRLs have had no significant impact on

these groundnut exports. The essay stresses the importance of addressing Africa's under-trading issue from a development perspective, focusing on domestic supply constraints before the border rather than on the excessive stringency of EU MRLs.

My second essay is a methodological contribution. I provide a parsimonious way to disentangle the role of SPS and technical measures as quality signals to consumers and as trade impediments through cost increases to producers and exporters. Unlike tariffs which always penalize consumers of the taxed commodities, SPS and technical measures can also enhance consumers' demand for the targeted products via quality signaling and by resolving informational asymmetries. The proposed methodology identifies the two effects separately and sheds light on how consumers and producers respond to these regulations. I apply the methodology to an empirical analysis of agricultural trade between OECD countries in 2004. I find that in aggregate, intra-OECD agricultural trade was actually facilitated by these technical measures rather than impeded, although both effects are clearly present. The application adds a new dimension to the continuing debate of "standards as catalysts" versus "standards as barriers" in the sense that both effects take place simultaneously and can be identified.

The third essay is an econometric contribution. It proposes a novel two-step estimator for the gravity equation model to trade that deals with two stylized features in trade data: prevalent zeros trade records and heteroskedasticity. I first conduct Monte-Carlo simulations to investigate how the proposed estimator performs relative to other well-known econometric techniques. In an analysis of world trade data in 1986, I further demonstrate the usefulness of the proposed estimator by providing a model selection strategy using specification tests. The results suggest that the proposed estimator dominates alternative estimators in presence of selection bias in data. The essay highlights how crucial the choice of estimator is in the quantification of the impact of trade barriers and trade costs on the decision to trade and the volume of trade.

CHAPTER 1: GENERAL INTRODUCTION

Introduction

With the previous and ongoing multilateral negotiations at the World Trade Organization (WTO) and a slew of regional agreements, there has been a world-wide decline in import tariffs (Aksoy and Beghin, 2005). In agricultural and food sectors, tariff liberalization has deepened since the enactment of the Agriculture Agreement of the WTO (WTO, 1995a). Meanwhile, the proliferation of standard-like Non-Tariff Measures (NTMs), including Sanitary and Phytosanitary (SPS) measures and Technical Barriers to Trade (TBTs), has raised concerns about their potential protectionism, especially in the North-South context (WTO, 1995b; WTO, 1995c). Because stringent NTMs could reduce or even offset gains from tariff liberalizations, sorting out the potential impact of these NTMs on trade and welfare is paramount to provide information to market participants affected by these measures, and to better guide policy design (WTO, 2005). In this dissertation, I provide three self-contained yet inter-related essays to guide the quantification of the impacts of standard-like NTMs and the relevant conceptual framework and econometric methodology required to assess these effects.

The gravity equation model has been widely used in the international trade literature to evaluate various trade-related policies. It explains the bilateral trade flow by the sizes of the trading countries and other variables that affect the costs of trading between the two countries (e.g., distance, import tariffs, colonial tie, adjacency, etc.). A natural extension of the gravity equation model to the policy analysis of the NTMs is to include the NTM variable of interest as an additional explanatory variable.[1] Unlike tariffs which impede international trade and in most instances decrease welfare, standard-like NTMs have more ambiguous effects on trade and welfare because they may alter consumers' quality perception for the targeted products besides raising producers' costs. Further, market imperfections may dictate corrective measures (such as country-of-origin labeling and additives prohibitions) to which consumers and producers react differently. Such interaction calls for the identification of the supply-shifting effect and the demand-shifting effect in the analysis of standard-like NTMs.

Last, in terms of econometric modeling, recent developments in the gravity equation approach highlight the challenges in the statistical estimation of a gravity equation model. On one hand, the frequent presence of zeros in trade data requires a proper strategy to deal with the potential sample selection bias (Heckman, 1979). On the other hand, heteroskedasticity in trade data often causes severe bias in the estimation of a logarithmically transformed gravity equation (Silva and Tenreyro, 2006). These empirical challenges call for the development a new estimator for the gravity equation model that can simultaneously deal with both problems. This is the motivational context of my dissertation.

In the first essay, I evaluate the impact of European Union (EU)'s harmonization and strengthening of aflatoxin Maximum Residue Limits (MRLs) on groundnut exports from Africa to EU markets. The World Bank predicted that the harmonization to tighter limits, with the associated MRLs below the international standards in Codex, would reduce Africa' groundnut exports by nearly 36% (Otsuki, Wilson and Sewadeh, 2001). However, by

[1] The political economy of the NTMs is beyond the scope of the dissertation. In general, the political economy of NTMs is more complex than that of tariffs because: (a) both public's rising awareness of sanitary threats and traditional protectionism effort are in play; (b) the relevant science is incomplete or the opinions on available scientific evidence are divided; and (c) the vagueness in notification and implementation of NTMs provides further room for political objectives. Interested readers are refereed to the World Trade Report (WTO, forthcoming) for a detailed discussion.

extending the original dataset to cover both the pre- and post-harmonization periods and employing advanced econometric techniques, I find that Africa's groundnut exports are more constrained by their domestic supply issues, rather than by EU's MRLs on aflatoxin residues. The result casts doubt on the conventional wisdom of "standards as barriers" and stresses the need to address African domestic supply constraints before the border. In addition to the policy findings, the essay provides an appropriate strategy to select the most suitable estimator among those readily available for the gravity equation estimation. The essay has been published in the *European Review of Agricultural Economics*.

My second essay proposes a conceptual framework and methodology to disentangle the demand-enhancing effect and the trade-cost effect of technical measures. Not only a technical measure increases producers' costs, it may also affect consumers' quality perception of the regulated commodities. Consequently, the overall effect of a technical measure on trade can be either negative or positive, depending on whether the trade-cost effect dominates or falls short of the demand-enhancing effect. Such analytical ambiguity is also supported by the empirical studies in the literature where mixed results are found: the impact of NTMs on trade can range from negative and statistically significant to positive and statistically significant (e.g., Jaffee and Masakure, 2005; Disdier et al., 2008; Anders and Caswell 2009). A proper disentanglement strategy is much in need to help distinguish a NTM addressing market imperfection affecting consumers from one predominately ridden by trade protectionism. I apply the proposed disentangling approach in an analysis of intra-OECD agricultural trade using data of Disdier et al. (2008). I find that technical measures boost consumers' demand more than they increase foreign exporters' costs, with a moderate positive net effect on the extensive margin of trade. The identification of the demand-enhancing effect of these NTMs tends to reject the conjecture that NTMs are purely protectionist in disguise.

In the last essay, I develop a two-step estimator for the gravity equation model that accommodates two stylized features of trade data: numerous zero observations and heteroskedasticity. Earlier efforts in the literature focus on either side of issue, without a consensus on how to deal with the two features simultaneously. The development of a solid estimator for the gravity equation model can better guide empirical investigations and lead to improved policy recommendations. My proposed two-step estimator works as follows. In the first step, zero trade records are explained by a selection process and the extensive margin of trade, i.e., the creation of new trade partnership, can be computed accordingly. In the second step, an augmented gravity equation with correction for the sample selection bias is estimated by a nonlinear least square procedure. Consequently, the intensive margin of trade, i.e., the expansion of pre-existing trade flows, is consistently derived even when trade data exhibit heteroskedasticity.

I first conduct Monte-Carlo experiments to investigate how the proposed estimator performs relative to other well-known econometric techniques such as the Poisson Pseudo Maximum Likelihood estimator (Silva and Tenreyro, 2006), the Heckman Sample Selection model (Heckman, 1979), and the E.T.-Tobit model (Eaton and Tamura, 1994). In an analysis of world trade data in 1986, I further demonstrate the usefulness of the proposed estimator by providing a model selection strategy using specification tests. The results suggest that that the proposed estimator dominates the alternative methods when the data exhibit non-random sample selection and heteroskedasticity in levels. The essay highlights how crucial the choice of estimator is in the quantification of the impact of trade barriers and trade costs on the decision to trade and the volume of trade.

In the rest of the dissertation, I present the three essays in Chapter 2, 3, and 4 respectively.

Conclusions and Policy Implications

To sum up, my three essays contribute to the knowledge of the impact of NTMs on international agricultural and food trade and develop new methodologies for the estimation of the gravity equation approach to trade. In the first essay, I find that Africa's groundnut exports are more restricted by their domestic issues, than by European Union's sanitary standards in aflatoxins. The results call for resolving the Africa' under-trading phenomenon (i.e., African countries export less to the world market than projected) from an international development perspective, such as improving the storage facilities and upgrading farming practices (IFPRI, 2012).

My second essay provides a method to disentangle the role of SPS/TBT measures as quality signals enhancing demand versus as trade impediments. The empirical application suggests that the intra-OECD agricultural trade was overall facilitated by technical regulations. The results point to the complexity of the impact of NTMs relative to traditional tariff schemes. Furthermore, the methodology in the essay serves as a first step to fully distinguish the NTMs with legitimate objectiveness from ones ridden by protectionism. An extension of this essay with full-fledged welfare analysis is in my post-dissertation research agenda.

A novel estimator is proposed in my last essay for the gravity equation approach to trade. The novel estimator successfully deals with two stylized features of trade data: heteroskedasticity and prevalent zero observations. This last essay contributes to the empirical trade literature by providing strong guidance for the appropriate selection of an estimation method in the quantification of the impacts of NTMs and other trade-related policies within the gravity equation framework.

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CHAPTER 2. DOES EUROPEAN AFLATOXIN REGULATION HURT GROUNDNUT EXPORTERS FROM AFRICA?

A paper forthcoming in *European Review of Agricultural Economics*

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Abstract

We provide an ex-post econometric examination of the harmonisation and tightening of the EU Maximum Residues Limit (MRL) on aflatoxins in 2002, and its impact on African exports of groundnut products. We find no evidence of the EU MRL having a significant negative trade impact on these groundnut exports from Africa across various methods of estimation. African domestic supply plays an important role in the determination of the volumes of trade and the propensity to trade. Our findings suggest that the trade potential of African groundnut exporters is more constrained by domestic supply issues rather than by limited market access.

Introduction

Aflatoxins are toxic metabolites produced by fungi in agricultural commodities. They are commonly found in corn, peanuts, coconuts, cassava and their processed forms. Aflatoxin B1, M1, and G1 can cause various types of cancer in both animal species and humans. Evidence of acute aflatoxicosis in humans has been reported from many parts of the world with grim morbidity and mortality. Chronic intake of aflatoxin in animals can lead to poor food intake and weight loss.

Aflatoxin regulations have received great attention in food policy design and debates. Good practice based on current scientific knowledge and technical improvements can reduce the level of contamination; however, the entire elimination of aflatoxins in foodstuffs is impossible. Maximum Residue Limits (MRLs) are commonly adopted as the policy instrument to control for aflatoxin contamination in the food supply. Tight aflatoxin MRLs generate health benefits but also induce various costs such as regulatory and administrative costs, compliance costs borne by producers, and plausible forgone trade revenues borne by some foreign exporters failing the MRLs.

The EU harmonization of MRLs on aflatoxins in 2002 has highlighted these controversial tradeoffs. Prior to 2002, EU member countries set their MRLs individually (FAO, 1995). In April 2002, the EU formally adopted a unified MRL policy on aflatoxin contaminants (European Communities, 2001 and 2002). In December 2006, the EU modified the harmonized maximum levels for certain contaminants in foodstuffs, but the policy regarding aflatoxin remained (European Communities, 2006). The harmonized EU aflatoxin standards have been more stringent than international standards of Codex Alimentarius of the Food and Agriculture Organization (FAO) and World Health Organization (WHO). First, the EU policy targets specific aflatoxin compounds. Not only the EU policy sets an MRL for the total aflatoxin level as Codex does, it also imposes an MRL on aflatoxin B1, which is the most toxic compound in the aflatoxin family. Second, the EU MRLs are lower than Codex. For instance, the EU harmonized MRLs on Aflatoxin B1 for edible groundnuts and shelled groundnuts are 2 ppb and 8 ppb respectively, compared to an estimate of 10 ppb for both products in Codex Alimentarius.[2] Within Europe, the harmonization has different implications for different groundnut products: the harmonization process forced many EU

[2] Codex Alimentarius sets a MRL of 15 ppb on total aflatoxin contaminants for edible groundnuts and shelled groundnuts. 70 per cent of total aflatoxins can be attributed to Aflatoxin B1. Therefore, the Codex MRL on Aflatoxin B1 is approximately 10 ppb for both products.

member countries to tighten their MRL for edible groundnuts but relax their MRL on shelled nuts significantly, except in Portugal, where both MRLs was much stricter than before. MRLs for oil were not subject to harmonization, but Switzerland, which follows EU regulation, relaxed its MRL on oil in 2002.

The strictness of the EU standards has triggered concerns that the EU has abused the Agreements on Sanitary and Phytosanitary (SPS) Measures of the World Trade Organization (WTO) and created a protectionist SPS regulation. Groundnut exporters from Africa, in particular, are considered vulnerable to the new regulations because of their high cost of compliance and their dependency on the EU market as their largest export destination.

Otsuki, Wilson and Sewadeh (2001), in a noted paper, examined this very issue in the late 1990s by conducting a gravity equation analysis to a pre-harmonization dataset of EU MRLs and trade flows. They found that the African exports of edible groundnuts and groundnut oil were constrained by the MRL on aflatoxin set by EU member countries during 1989-1998. Their simulation predicted that the harmonization and tightening of the standards in 2002 would decrease African exports enormously. Their analysis has two limitations. The first one is the lack of time-variation of the MRL variable. The research was done before the harmonization took place in 2002. During the period of examination, 1989-1998, the only available data source for the MRL policies on aflatoxin was FAO (1995) reporting 1995 MRLs. Consequently, the 1995 MRL was assumed to hold for the entire time period and only exhibited cross-sectional variation. As we will elaborate later, this lack of time-variation of the MRL variable makes its effect undistinguishable from the country-level 'multilateral resistance' terms or fixed effects (Anderson and van Wincoop, 2003).

The second limitation in Otsuki, Wilson, and Sewadeh (2001) comes from their deletion of the zero trade records. Statistically, the elimination of zeros could result in the standard sample selection bias (Heckman, 1979). Even if the sample selection issue does not bias the estimate of interest, the ignorance of zero trade flows limits the economic interpretations of the model. First, the deletion of the zero trade precludes exploring the extensive margin of trade, that is, the creation of new bilateral trade partnership, and the role of MRL on this margin. In addition, all their estimates are conditioned on trade already taking place, and marginal effects of SPS measures and other trade costs are on the intensive margin of trade. Nothing could be said on implications for new trade.

The harmonized EU aflatoxin regulations have been in place for several years and remain a plausible factor contributing to the vulnerability of African groundnut export potential and market access. It is of much interest to reconsider the previous analysis and re-examine whether groundnut exporters from Africa actually turn out to be impeded by the new EU standards. This issue remains a major concern with development practitioners. For example, International Food Policy Research Institute (IFPRI) has several field projects exploring the impact of aflatoxin MRLs on small African holders and how to overcome phytosanitary issues in production and trade (IFPRI, 2009). Our investigation complements this current fieldwork on aflatoxin and associated trade impediments.

Our analysis also contributes to the debate on Africa's 'under-trading' (Bouët, Mishra and Roy, 2008). Africa trades less with the rest of the world than one would expect, according to various economic models, even after controlling for major trade costs and the size of the trading economies. It remains a puzzle whether this African missing trade is more associated with the limited access to the world market or to domestic factors within Africa. Bouët, Mishra and Roy (2008) incorporate various trade barriers in a gravity equation analysis and find that African countries in general already have good market access, and that the transport and communication infrastructure can be held accountable for the under-trading phenomenon. Other authors have emphasized the poor internal infrastructure of African countries (Buys, Deichmann, and Wheeler, 2010).

Our objective is to provide an ex-post econometric examination of the harmonization and tightening of EU MRLs on aflatoxins in 2002, and its impact on African exports of groundnut products. By virtue of a state-of-the-art gravity model with corrections for the sample selection bias, the ‘multilateral resistance’ terms, and the heterogeneity across firms, we have two main findings. First, EU MRLs have no significant impact on groundnut exports from Africa across all preferred methods of estimation. Two rationalizations can help interpret this result. Either, the MRL regulations are non binding for African groundnut exporters because other factors in production and before the border are binding impediments. As discussed below, our second result favors this rationalization. Or, alternatively, the tighter MRL on aflatoxin does induce additional trade costs to African groundnut exporters, but it also generates trade benefits because EU consumers value safer groundnut products from Africa. The two effects could systematically offset each other, thus the net effect on trade is negligible.

The second finding is that domestic supply conditions in Africa play an important role in the determination of both the trade volumes and the propensity to trade in groundnut products. This result is consistent with the recent findings of Bouët, Mishra, and Roy (2008) on the lack of trade facilitation in Sub-Saharan Africa for all exports, and the extent to which the missing trade is self-inflicted. Rios and Jaffee (2008) and Jaffee and Henson (2004) state that in several cases, inspections reveal extreme violations of MRL regulations by African exports, including violations of codex MRLs making the EU MRLs redundant. Consistent with the latter, our findings cast doubt on the conventional wisdom of restrictive EU aflatoxin regulations. They suggest the key importance of addressing domestic issues in production and trade facilitation in Africa. In terms of groundnut products, improving the farm-level practice could reduce the aflatoxin contaminants, increase yields, and eventually lead to more trade. These improvements would lead to more consistent production of exportable products which could meet the MRLs.

The analysis is organized into five sections. Section 2 outlines our empirical strategy and describes the data set. Section 3 provides several model specifications and proposes a model selection strategy. Section 4 reports the associated results from the preferred models. Section 5 checks the robustness of the main results, and summarizes the trade effects of the MRL policy. Section 6 concludes the presentation.

Methodology and Empirical Strategy

Gravity equation models are widely used to infer trade flow effects of distance (Disdier and Head, 2008), common borders (McCallum, 1995), tariffs (Baier and Bergstrand, 2001), technical barriers to trade (TBTs) (Maskus and Wilson, 2001), fixed trade cost between countries (Helpman, Melitz and Rubinstein, 2008), and other trade costs. The gravity equation approach posits that bilateral trade volume is a function of the importer's demand, the exporter's supply, and various bilateral trade costs such as tariffs, technical barriers, transportation costs, border effects, colonial ties, etc. Gravity equations fit the data well across a wide range of applications in international trade and are a popular tool. Despite this popularity, recent research has investigated several widespread mistakes and biases present in gravity equation applications (Anderson and van Wincoop, 2003; Baldwin and Taglioni, 2006; Helpman, Melitz and Rubinstein, 2008; and Martin and Pham, 2008).

Structural shortcomings have been emphasized by Anderson and van Wincoop (2003) and Baldwin and Taglioni (2006). Well specified models should lead to 'multilateral resistance' terms which are often omitted in gravity equation specifications. When included, these effects are often captured by importer and exporter fixed effects. Further literature sheds light on several econometric problems associated with the gravity equation that are relevant to our analysis. The first problem is the sample selection bias, as originally defined by Heckman (1979). A commonly found feature in bilateral trade data is that zero trade records are frequent across country-pairs and products, and that the zero trade flows could dominate when disaggregated trade data are used. Martin and Pham (2008) show that failure in modeling such limited dependency of the trade data can result in large biases for all estimates of interest. Helpman, Melitz, and Rubinstein (2008) attribute the absence of trade to exporting firms' self-selection behavior when they exhibit heterogeneous productivity. Only the most productive firms export leading to an extensive margin from new firms entering export markets. The estimation of their generalized gravity equation model does not require firm level data and is implemented via a two-stage modified Heckman procedure.

Heteroscedasticity is the second econometric problem associated with gravity equation models. Because of the Jensen's Inequality, the parameters of a log-linearized gravity equation can not be interpreted as the true elasticities (Silva and Tenreyro, 2006). Silva and Tenreyro estimate the gravity equation in its original multiplicative form in levels using a Poisson Pseudo-Maximum-Likelihood (PPML thereafter) method. Martin and Pham (2008) compare different estimators in a Monte-Carlo experiment in which both prevalence of zero trade and heteroskedasticity are present. Their results show that the Heckman Maximum Likelihood estimator performs well if true identifying restrictions are available, and that PPML solves the heteroskedasticity problem but yields biased estimates when zero trade observations are frequent. In an application to the exports of US corn seeds, Jayasinghe, Beghin and Moschini (2010) find that PPML does not accommodate pervasive zeros well.

Burger, Van Oort, and Linders (2009) suggest that some variants of the PPML estimator accommodate greater dispersion of the data than implied by the Poisson distribution and the presence of numerous zero observations using a ‘zero inflation equation.’ These variants are the Negative Binomial Pseudo Maximum Likelihood estimator (NBPML thereafter), the Zero-Inflated Poisson Pseudo Maximum Likelihood model (ZIPPML thereafter), and the Zero-Inflated Negative Binomial Pseudo Maximum Likelihood model (ZINBPML thereafter). These models often outperform PPML in empirical trade applications with frequent zero trade flows.

To address the co-existence of the pervasive zero trade flows and the heteroskedasticity issue, the selection of a preferred estimator is guided by empirical results. We consider Truncated Sample Ordinary Least Square (a reference benchmark), the Helpman-Melitz-Rubinstein (HMR) generalized gravity equation model, and the pseudo maximum likelihood estimators (PPML, NBPML, ZIPPML, and ZINBPML), followed by a model selection strategy. Inferences are then drawn upon the econometric results to select the preferred models. Next we describe the data and then move into the model specification and selection.

Data Description

Our dataset builds upon the dataset of Otsuki, Wilson, and Sewadeh (2001) considering edible groundnuts, groundnut oil, and shelled groundnut (groundnut for further processing). Bilateral trade volumes of each groundnut product between 14 European countries (13 EU members: Austria, Belgium-Luxemburg, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, plus Switzerland[3]), and nine African countries (Chad, Egypt, Gambia, Mali, Nigeria, Sudan, Senegal, South Africa, and Zimbabwe) are extracted from United Nations COMTRADE for the period 1989-2006.[4] For MRL levels, we use FAO's survey of worldwide regulations for mycotoxins in food and feed (FAO, 1995), and Commission Regulation No 466/2001 on setting maximum levels for certain contaminants in foodstuffs (European Commission, 2001). With these two sources, we construct an MRL variable that indicates the MRLs on aflatoxin B1 imposed by each EU member country in each year.[5]

The income argument in any EU member country's demand for groundnut exports is represented by its GDP expressed in local currency units from the World Development Indicators of The World Bank for any given year. The annual domestic supply of a groundnut product in a given African country is proxied by its total exports to the rest of the world of that product.[6] To deal with the potential endogeneity associated this proxy, we also extract

[3] We refer to all 14 importers of interest as EU member countries or the EU hereafter including Switzerland which has aflatoxin MRLs similar to the EU MRLs but is not a member of the EU.
[4] SITC Revision 1 codes 05172, 2211 and 4214 are used as the product categories for edible groundnut, shelled groundnut and groundnut oil.
[5] We follow Otsuki, Wilson, and Sewadeh (2001) and assume that the MRLs reported in FAO (1995) hold for the period 1989-2001. The harmonized MRLs cover the period 2002-2006. For Switzerland, the MRLs after 2001 follow FAO (2004).
[6] Consumption data in Africa is not systematically available. Consumption is often made of nontraded lower quality. We assume that domestic consumption takes a negligible share in the supply of the higher quality exportables.

food supply series from FAOSTAT database for robustness' check. Our dataset also contains a distance variable measuring the capital distances between country pairs, a colonial tie dummy indicating whether trading partners had colonial relationship in history as described in Otsuki, Wilson, and Sewadeh (2001), and a common language dummy that equals one if a language is spoken by at least 9 per cent of the population in both countries.[7]

Three features of our dataset are outstanding. First of all, zeros dominate the trade records in all three groundnut products. 88 per cent of the bilateral trade flows in edible groundnut between African countries and the EU are zeros. This percentage is 90 per cent for groundnut oil and 81 per cent for shelled groundnut. Some of these zero trade observations may be due to rounding errors or incompleteness of the COMTRADE, but many others are more likely to reflect African exporters' reluctance or inability to trade. The latter could result from prohibitive fixed cost to establish trade partnership with the EU member countries, including compliance costs to meet the restrictive standards. Therefore, it is necessary to explicitly model this limited-dependency of the trade data to accommodate the absence of trade. Second, the MRL variable exhibits time variation due to the EU harmonization of aflatoxin regulations in 2002, which allows us to disentangle the trade effect of the MRL policy out of the country-level fixed effects. Lastly, our supply proxy originates in the sectoral approach of the gravity equation and it is a supply measure in physical quantity rather than the GDP of the exporter.[8] We express the supply in physical form (metric tons) as we deal with disaggregated commodities.

[7] Tariffs could matter. TRAINS data show that EU tariffs faced by African countries are mostly zero from 1995 on. Pre-1995 tariff are not in TRAINS. TARIC has some pre-1995 information. The available data exhibits little variation across the importers and over time. We capture the effect of tariffs with time fixed effects.
[8] Henry de Frahan and Vancauteren (2006) provide a brief discussion of the sectoral gravity equation application to disaggregated trade data.

Model Specifications and Model Selection

We consider three estimation alternatives for the gravity equation model. The first one is the Truncated Sample Ordinary Least Square (Trun-OLS hereafter), which is commonly used in the literature. It is an Ordinary Least Square estimator applied to the subsample of positive observations.[9] The Trun-OLS estimator suffers from several criticisms. One major statistical problem is the potential sample selection bias it can cause if the eliminated zero observations are not drawn on a random basis. This is potentially our case since countries choose voluntarily not to trade with each other. Even if a sample selection bias is not detected, the economic interpretations of truncated OLS estimates are limited. In our application, a Trun-OLS estimate only captures the intensive margin to trade, the intensification of existing trade. However, from a development viewpoint it is the creation of new bilateral trade partnerships (the extensive margin) that we are interested in. Have the harmonization and tightening of the EU aflatoxin regulation decreased the international market accessibility for groundnut exporters from Africa? The latter concern naturally motivates a Heckman-type sample selection model.

We choose the HMR approach which is the state-of-the-art of the gravity equation approach to trade with sample selection. The HMR approach generates an extended gravity equation model with firm-level heterogeneity in productivity with three positive features. First, it explains zero trade flows. The absence of bilateral trade occurs when all producers, even the most efficient ones, within a country find it unprofitable to export to a destination. Second, HMR addresses the sample selection bias (Heckman, 1979). A selection equation

[9] We use the Trun-OLS model to test the endogeneity of the MRL variable using the one-year-lagged MRL as the instrument. The Durbin-Wu-Hausman test cannot reject the null hypothesis that the MRL variable is exogenous to trade.

accounts for the qualitative choice of outcomes, whether or not to trade with an EU country in our context. This selection equation and the outcome equations (the equation with positive observations only) are jointly estimated via a maximum likelihood method or a two-step procedure.

Third, HMR controls for the trade effect of the fraction of exporting firms, which varies across exporting countries due to the different degrees of firm-level heterogeneity. Only the most productive firms export because exports entail some additional fixed costs relative to selling domestically. Econometrically, this additional term in the outcome equation can be consistently estimated from the first stage of the Heckman two-stage procedure. To help with the identification, one explanatory variable included in the selection equation is excluded from the outcome equation. Economic theory suggests that a variable that affects the fixed costs of EU-African trade, but not the variable costs of trade, would qualify. We let the colony dummy variable serve this role.[10] The HMR in our application is specified as follows:

$$\begin{aligned}(1)\quad \Pr(Y_{ijt}^k > 0) = \Phi(&\tilde{\beta}_0^k + \tilde{\beta}_1^k \ln(MRL_{jt}^k) + \tilde{\beta}_2^k \ln(GDP_{jt}) + \tilde{\beta}_3^k \ln(Supply_{it}^k) + \tilde{\beta}_4^k \ln(Dist_{ij}) \\ &+ \tilde{\beta}_5^k Dlang_{ij} + \tilde{\beta}_6^k Dcol_{ij} + \sum_{t=1}^{18} \tilde{\alpha}_t^k Year_t + \sum_{m=1}^{8} \tilde{\gamma}_m^k Dex_m + \sum_{n=1}^{13} \tilde{\eta}_n^k Dim_n),\end{aligned}$$

$$\begin{aligned}(2)\quad \ln(Y_{ijt}^k \mid Y_{ijt}^k > 0) = {}&\beta_0^k + \beta_1^k \ln(MRL_{jt}^k) + \beta_2^k \ln(GDP_{jt}) + \beta_3^k \ln(Supply_{it}^k) + \beta_4^k \ln(Dist_{ij}) \\ &+ \beta_5^k Dlang_{ij} + \sum_{t=1}^{18} \alpha_t^k Year_t + \sum_{m=1}^{8} \gamma_m^k Dex_m + \sum_{n=1}^{13} \eta_n^k Dim_n \\ &+ \ln\{\exp[\delta^k(\hat{z}_{ijt}^k + IMR_{ijt}^k)] - 1\} + \eta^k IMR_{ijt}^k + \mu_{ijt}.\end{aligned}$$

The definition of each variable is presented in Table 1.

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[10] The colony dummy is empirically preferable to the common language dummy as the excluded variable because it stands out significant in the selection equation in two out of the three products, while the common language has null explanatory power on any selection equations (see Table 3). The common language variable also leads to convergence problems in HMR when used as the excluded variable.

Table 1. Definitions of variables

Variable name	Definition
Y_{ijt}^{k}	The quantity traded of groundnut product *k* from African country *i* to EU member country *j* in year *t*
MRL_{jt}^{k}	The MRL applied to groundnut product *k* set by EU member country *j* in year *t*
GDP_{jt}	The GDP (in local currency unit) of EU member country *j* in year *t*
$Supply_{it}^{k}$	The total supply of groundnut product *k* in African country *i* in year *t*
$Dist_{ij}$	The distance between African country *i* and EU member country *j*
$Dlang_{ij}$	The common language dummy variable for African country *i* and EU member country *j*
$Dcol_{ij}$	The colonial tie dummy variable for African country *i* and EU member country *j*
$Year_{t}$	The dummy variable for year *t*
Dex_{m}	The national dummy for African country *m*[a, c]
Dim_{n}	The national dummy for EU member country *n*[b, c]

Note: a. South Africa is the reference country among the exporters whose national dummy is suppressed. b. France is the reference country among importers whose national dummy is suppressed. c. Although time-varying national fixed effects are more desirable, the inclusion of time-varying importers' fixed effects would be perfectly collinear with the MRL variable and fully absorb its effects.

Selection equation (1) is essentially a standard Probit binary choice model, where $\Phi(\bullet)$ is the standard normal distribution function. We assume that the colonial tie dummy variable affects the fixed cost of trade, but has negligible effects on the variable costs to trade. Variables β_s, α_s, γ_s, and η_s are parameters to be estimated. A positive β_1 suggests that the MRL on aflatoxin constrains trade. In Equation (2), the term $\ln\{\exp[\delta^k(\hat{z}_{ijt}^k + IMR_{ijt}^k)] - 1\}$ captures the trade effect of the fraction of firms in country *i* that export to country *j* in year *t*.[11] Specifically, $\delta^k > 0$ is a parameter to be estimated: a larger δ^k corresponds to a greater degree of heterogeneity in productivity across firms in sector *k*, with more unproductive firms and fewer productive ones. $\hat{z}_{ijt}^k$ is the linear prediction calculated from estimates of (1).

[11] Readers are referred to Equation (14) in HMR for its derivation.

The inverse Mill's ratio, IMR_{ijt}^{k}, computed from the estimates in (1) as well, controls for the standard sample selection errors as in Heckman (1979). We follow HMR to consistently estimate the model through a two-step procedure.[12] In the first step, (1) is estimated via Maximum Likelihood method, and the predicted probability to trade $\hat{z}_{ijt}^{k}$ and Inverse Mill's Ratios IMR_{ijt}^{k} can be computed accordingly. In the second step, (2) is estimated via Non-Linear Least Squares.

Another concern with the gravity equation approach is the inherent heteroskedasticity in the trade data combined with the log-linearization of the original multiplicative form of the gravity equation leading to biases in elasticity estimates. To address this concern, we follow Silva and Tenreyro (2006) and Burger, Van Oort, and Linders (2009) to re-estimate the gravity equation in levels via the pseudo maximum likelihood estimators. The PPML estimator proposed by Silva and Tenreyro (2006) has been shown to be robust to various heteroskedastic patterns as long as the conditional variance of the dependent variable is proportional to its conditional mean. However, this condition can be violated when the data exhibits excessive zero outcomes. The excessive zeros can either result from the over-dispersion of the data generating process, or the existence of another data generating process that produces inflated zeros (Greene, 1994). In order to accommodate those excessive zeros and identify their underlying processes, variants of PPML such as NBPML, ZIPPML, and ZINBPML are used and statistical tests lead to selecting a preferred variant. All four pseudo maximum likelihood estimators numerically allow for zero observations.

The specification of the PPML model is as follows:

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[12] Though desirable to estimate the model via a joint Maximum Likelihood method for efficiency consideration, the non-linearity of the outcome equation makes the log-likelihood function intractable.

$$E(Y_{ij}^k \mid X_{ijt}^k) = \exp[\beta_0^k + \beta_1^k \ln(MRL_{jt}^k) + \beta_2^k \ln(GDP_{jt}) + \beta_3^k \ln(Supply_{it}^k) + \beta_4^k \ln(Dist_{ij}) \quad (3)$$
$$+\beta_5^k Dlang_{ij} + \beta_6^k Dcol_{ij} + \sum_{t=1}^{18} \alpha_t^k Year_t + \sum_{m=1}^{8} \gamma_m^k Dex_m + \sum_{n=1}^{13} \eta_n^k Dim_n],$$

where X_{ijt}^k is the matrix containing all explanatory variables under consideration. The consistency of the PPML estimator is insured assuming $Var(Y_{ijt}^k \mid X_{ijt}^k) \infty E(Y_{ijt}^k \mid X_{ijt}^k)$. The conditional mean of the NBPML model is also based on (3), but allowing for over-dispersion, $Var(Y_{ijt}^k \mid X_{ijt}^k) \infty E^2(Y_{ijt}^k \mid X_{ijt}^k)$.

The zero-inflated variants, ZIPPML and ZINBPML, are specified in the following way:

$$(4) \quad \Pr(Y_{ijt}^k = y \mid x_{ijt}^k) = \begin{cases} \Phi(x_{ijt}^k \gamma^k) + (1 - \Phi(x_{ijt}^k \gamma^k)) f(0 \mid x_{ijt}^k) & if \quad y = 0, \\ (1 - \Phi(x_{ijt}^k \gamma^k)) f(y \mid x_{ijt}^k) & if \quad y > 0, \end{cases}$$

where $\Phi(x_{ijt}^k \gamma^k)$ is the probability of zero trade flows due to exporters' decision to be absent from the export market, $f(\bullet)$ is the density function of the data generating process that produces the levels of trade flows conditioning on the decision to trade. With the ZIPPML method, the data generating process has a mean of (3), and $Var(Y_{ijt}^k \mid X_{ijt}^k) \infty E(Y_{ijt}^k \mid X_{ijt}^k)$. In ZINBPML, the data generating process has the same mean, but $Var(Y_{ijt}^k \mid X_{ijt}^k) \infty E^2(Y_{ijt}^k \mid X_{ijt}^k)$. Notably, there are two sources of zero trade flows in the zero-inflated models. Either, an exporter decides not to trade in the first stage, or it decides to trade but is hit by a negative cost shock which makes the trade volumes zero. As in the HMR model and for consistency across selection and inflation equations, we assume that the colonial tie between countries tends to affect the decision to trade, but not the conditional trade volumes.

To sum up, we consider all four pseudo maximum likelihood estimators, with associated tests to select the proper model. First, the difference between PPML and ZIPPML (as well as for NBPML and ZINBPML) hinges on the existence of another data generating process that produces excessive zeros caused by self-selection into no trade. A Vuong test (Vuong, 1989) is used to distinguish the zero-inflated model and its regular counterpart. Second, ZIPPML is a special case of ZINBPML when over-dispersion is not established in the data generating process of the trade levels. Statistically, the existence of over-dispersion is tested using a standard likelihood-ratio test (with the null hypothesis that the dependent variable exhibits equi-dispersion). NBPML nests PPML as a special case in a similar way. Now we propose a model selection strategy via which we can compare above-mentioned models based on both economic theory and the relevant statistical tests. Table 2 summarizes the features of each model and suggests a roadmap for selection. We choose the most preferable model via the elimination of the dominated models.

Table 2. Model selection for all three groundnut products

Model	Trun-OLS	HMR	Pseudo maximum likelihood estimators			
			PPML	NBPML	ZIPPML	ZINBPML
Model features						
Selection/inflation process	no	yes	no	no	yes	yes
Correction for selection bias	no	yes	no	no	no	no
Trade effect of new entrants	no	yes	no	no	no	no
Robustness to heteroskedasticity	no	no	yes	no	no	no
Tests on the family of pseudo maximum likelihood estimators						
Dispersion test	-	-	PPML $\prec$ NBPML		ZIPPML $\prec$ ZINBPML	
Vuong test	-	-		PPML $\prec$ ZIPPML		-
			-		NBPML $\prec$ ZINBPML	

Notes: More details on the statistical tests are presented in Table 5.

First of all, the Truncated OLS model is considered inferior to others because of its inability to address zeros and new market access, its potential biasness from sample selection, and vulnerability to heteroskedasticity. Secondly, the dispersion and Vuong tests lead to the ZINBPML model as the most suited model within the family of pseudo maximum likelihood estimators for all three groundnut products. Therefore, the model choice boils down to the comparison between the HMR model and the ZINBPML model. As Table 2 shows, the HMR model has the advantages of correcting for the potential sample selection bias, that is, the information one can infer about the trade volume once we know an exporter decides to export to a destination; and modeling the trade effect of newly entrants to the export market in a theoretically rigorous and econometrically applicable way. However, the ZINBPML model is able to accommodate both the decision to trade and the over-dispersion of trade, commonly found in disaggregated data. In fact, there are no existing statistical methods to distinguish the two models methodologically, suggesting that the choice between HMR and ZINBPML is case specific. Since we find evidence of the mis-specification of firms' margins and biasness due to logarithmic transformation (see Table 4 below), one could consider ZINBPML to be preferable to HMR.

Model Results and Discussions

The HMR results are reported in Table 3.[13] We discuss the estimates in the selection equations and the outcome equations, in turn. Two interesting findings come from the estimated selection equation. First, the decision of trade or not is indeed an endogenous outcome as we expect. The estimates in the selection equations show that a larger European

[13] We also estimate the model via standard Heckman Maximum Likelihood method without controlling for the firm-level heterogeneity. The estimates, with new firms margins absent, are qualitatively similar to those in Table 3.

GDP, a more abundant supply, or a historical colonial tie helps create new trade partnership between the African groundnut exporters and the European importers. Second, the MRL policy on aflatoxin has very little impact on the extensive margin to trade. In other words, the MRL policy on aflatoxin imposed by the EU does not appear to decrease market access for African exporters.

The estimates in the outcome equations convey two important messages. First, the MRL imposed by the EU has negligible effects on either existing exporters or newly entered exporters from Africa, which contradicts the previous finding by Otsuki, Wilson, and Sewadeh (2001).[14] The P-values associated with the MRL estimates suggest that the policy is not statistically significant at 10 per cent level for any groundnut product under consideration. Second, among all other bilateral trade determinants, African domestic supply is the only systematic contributor to exporting all three products, suggesting the key importance of domestic production capacity in Africa to explain its trade potential.

Table 3. Helpman-Melitz-Rubinstein models

	Edible groundnut			Shelled groundnut			Groundnut oil		
	Exten. margin[a]	Existing firms' margin[b]	New firms' margin[c]	Exten. margin[a]	Existing firms' margin[b]	New firms' margin[c]	Exten. margin[a]	Existing firms' margin[b]	New firms' margin[c]
MRL	-0.165 (0.280)	-0.408 (0.271)	-0.123 (0.263)	-0.030 (0.807)	0.031 (0.926)	-0.013 (0.836)	0.759 (0.234)	1.006 (0.497)	0.287 (0.271)
GDP	1.156♦ (0.001)	-7.150♦ (0.001)	0.825♦ (0.001)	0.820 (0.177)	0.089 (0.963)	0.398 (0.139)	1.602♦ (0.000)	-4.007 (0.311)	0.645♦ (0.000)
Supply	0.073** (0.035)	0.441♦ (0.001)	0.053** (0.029)	0.363♦ (0.000)	0.276 (0.123)	0.164♦ (0.000)	0.272♦ (0.000)	0.836* (0.076)	0.105♦ (0.000)
Dist	1.268♦ (0.002)	-0.395 (0.841)	0.903♦ (0.003)	0.699** (0.012)	-1.403 (0.291)	0.320** (0.013)	-1.634♦ (0.009)	-7.372** (0.046)	-0.649♦ (0.004)
Dlang	-0.264 (0.345)	1.082 (0.279)	-0.200 (0.330)	0.122 (0.520)	-1.399♦ (0.002)	0.043 (0.594)	-0.046 (0.855)	0.360 (0.301)	-0.028 (0.778)

[14] To detect the possible long-run effect of MRLs, we also add a new variable, MRL interacting with a linear time trend, and re-estimate the model. The estimate of the new variable is insignificant across all three products.

Table 3. (continued)

	Edible groundnut			Shelled groundnut			Groundnut oil		
	Exten. margin[a]	Existing firms' margin[b]	New firms' margin[c]	Exten. margin[a]	Existing firms' margin[b]	New firms' margin[c]	Exten. margin[a]	Existing firms' margin[b]	New firms' margin[c]
Dcol[d]	0.913♦ (0.005)		0.678♦ (0.004)	1.202♦ (0.000)		0.544♦ (0.000)	0.288 (0.321)		0.127 (0.277)
IMR[e]		0.764 (0.456)			0.136 (0.821)			0.590 (0.757)	
Obs.	1736	287		2156	462		1470	231	

Notes: a. The extensive margin is defined as the derivative of the logarithmic-scaled probability of trade with respect to the exogenous variable of interest. (see Appendix in supplementary data at *ERAE* online for details). b. The existing firms' margin corresponds to the estimate in (2), the second step of HMR. (see Appendix in supplementary data at *ERAE* online for details). c. The new firms' margin is defined as the derivative of the non-linear term in (2), the second step of HMR, with respect to the exogenous variable of interest. (see Appendix in supplementary data at *ERAE* online for details). The associated P values are based on bootstrapped standard errors. d. *Dcol* is excluded from the outcome equations for the identification purpose. e. The Inverse Mill's Ratio, computed from the estimates in the first-stage selection equations, corrects for the sample selection bias in the outcome equations. P-values are in parenthesis. *, **, and ♦ denote 10, 5, and 1 per cent significance level, respectively.

Two alternative rationalizations can help interpret the null effect of the EU MRLs. Either, most African exporters have difficulty meeting standards either before or after the harmonization, while a few well-established firms are able to comply with new regulations at little additional costs. Therefore, the change in MRLs only affects a handful of marginal firms. Or, the potential trade loss of African groundnut exporters due to the compliance cost associated with the tighter standard is offset by the trade benefits originated from an enhanced EU demand given consumers' preferences for safer groundnut products.[15]

We now turn to the effects of other trade cost terms. A larger European income appears to encourage trade in edible groundnuts, with incumbent firms being crowded out to some extent; whereas income does not seem to influence the trade in shelled groundnut much but tend to promote the propensity to trade groundnut oil. The importer fixed effects may also account for some of the income variation across EU countries. A longer distance decreases the sales of currently exporting firms for all three products but its effects on the

[15] The evolution of retail prices could help distinguish the two rationalizations. Unfortunately, the retail price series of African groundnut products sold in EU markets are not currently available.

two other margins in edible groundnuts and shelled groundnuts are unexpected. A colonial tie in history promotes the creation of new trade and is statistically significant for two out of the three products, which in part confirms its qualification as the excluded variable. The role of the common language is insignificant across margins and products expect that it has a significantly negative effect on the incumbents in the sector of shelled groundnuts, which is also unexpected.

The sample selection term, represented by the Inverse Mill's Ratio, turns out not statistically significant for all three groundnut products. The findings on the new firms' margins exhibit three notable features. First of all, some trade cost terms do affect trade flows through altering the behavior of new entrants, as evidenced by several significant new firms' margins in Table 3. This result underscores the importance of controlling for the new firms' margins. Secondly, a trade cost term can have very different impact on the incumbents versus new entrants. For example, the EU income response for edible groundnuts and groundnut oil from Africa suggests they are probably inferior products (negative income response in the existing firms' margin), although new trade of these products, both at the country-level (extensive margins) and at the firm-level (new firms' margin), is more likely to occur with large EU countries. Lastly, the existing firms' margin does not always dominate the new firms' margin. Although the existing firms' margin is larger in magnitude for most variables in Table 3, the income effects in the sector of groundnut oil indicate that sometimes newly entered firms are more sensitive to certain market conditions than incumbents.

Although firmly grounded in economic theory, the HMR model suffers from two major critiques. The logarithmic transformation of the trade flows in the outcome equation could lead to biased estimates of the elasticities. The logarithmic transformation often leads to correlation between the error terms and exogenous variables, thus to biased elasticity estimates in the outcome equations (Silva and Tenreyro, 2006). The Ramsey specification test (Ramsey, 1969) can be used to detect whether the outcome equations are correctly specified. The other concern, raised by Silva and Tenreyro (2009), is that the non-linear term capturing the trade effects of new firms is mis-specified if the selection equation in HMR exhibits heteroskedasticity. Therefore, a heteroskedasticity test on the first-stage Probit models should be used for diagnostic purpose. We report the two tests in Table 4. The Ramsey test results show that the elasticity estimates in the outcome equation for groundnut oil could be biased severely due to the logarithmic transformation. The homoskedasticity tests suggest that the decision to trade exhibits a great degree of heteroskedasticity in all three products, implying that the non-linear term in the second-stage of the HMR model is mis-specified.

Table 4. Tests on the HMR models

	Edible groundnut		Shelled groundnut		Groundnut oil	
Ramsey test on outcome equations	F-stat	P value	F-stat	P value	F-stat	P value
H_0: no specification error. [a]	0.02	0.899	1.48	0.224	3.91	0.049
Heteroskedasticity test on selection equations	χ^2-stat	P value	χ^2-stat	P value	χ^2-stat	P value
H_0: homoskedasticity. [b]	33.36	0.000	11.50	0.001	19.81	0.000

Notes: a. Following Silva and Tenreyro (2006), the squared fitted value is used as the additional regressor in the auxiliary regression of the test. The significance of this additional regressor suggests the mis-specification of the model. b. The alternative hypothesis is that the variance of the selection equations is proportional to the magnitude of African supply. H_0 is rejected if African supply significantly explains the variance.

Now we turn to the ZINBPML model, which is preferred model among the Pseudo Maximum Likelihood estimators based on the relevant statistical tests. Table 5 reports the ZINBPML model results for all three products, along with the Vuong tests and dispersion tests.[16] The likelihood ratio tests of the possible over-dispersion indicate that trade flows in all three products are significantly over-dispersed, whether or not a different process is in place to account for the decision to trade. Therefore, PPML and ZIPPML are dominated by NBPML and ZINBPML respectively. The additional Vuong tests show that PPML and NBPML are inferior to their zero-inflated variants ZIPPML and ZINBPML, implying that a binary choice process is indeed necessary to account for exporters' self-selection to not trade.

Table 5. ZINBPML models

	Edible groundnuts		Shelled groundnuts		Groundnut oil	
Model	Extensive margin[a]	Intensive margin[b]	Extensive margin[a]	Intensive margin[b]	Extensive margin[a]	Intensive margin[b]
MRL	-0.504	-0.697*	-0.139	0.248	2.090	1.034
	(0.271)	(0.075)	(0.639)	(0.346)	(0.175)	(0.208)
GDP	4.613♦	-5.743♦	2.279	1.088	4.352♦	-1.335
	(0.000)	(0.000)	(0.107)	(0.355)	(0.000)	(0.515)
Supply	-0.216*	0.447**	0.694♦	0.653♦	0.739♦	0.737♦
	(0.066)	(0.035)	(0.000)	(0.000)	(0.000)	(0.000)
Dist	-3.186**	4.684♦	1.988♦	-1.452	-4.440♦	-6.768♦
	(0.032)	(0.004)	(0.004)	(0.566)	(0.004)	(0.000)
Dcol	1.057		2.463♦		0.744	
	(0.237)		(0.000)		(0.283)	
dlang	-0.323	0.472	0.952**	-1.121♦	-0.133	0.422**
	(0.730)	(0.636)	(0.016)	(0.000)	(0.844)	(0.016)
Dispersion	3.292♦		2.090♦		0.702♦	
	(0.000)		(0.000)		(0.000)	
Vuong Statistic[c] (P value)	7.15♦ (0.000)		8.97♦ (0.000)		7.09♦ (0.000)	

Notes: a. The extensive margin is defined as the derivative of the logarithm-scaled probability of trade with respect to the variable of interest. (see Appendix in supplementary data at ERAE online for details). The associated P values are based on bootstrapped standard errors. b. The intensive margin is defined as the elasticity of trade levels with respect to the variable of interest, corresponding to raw coefficients in the outcome equations. (see Appendix in supplementary data at *ERAE* online for details). P-values are in parenthesis. *, **, and ♦ denote 10, 5, and 1 per cent significance level, respectively.

As shown in Table 5, the MRL shows no significant impact on either trade volume or

[16] The Vuong test is a likelihood ratio test. The associated statistic is normally distributed, with a large positive value in favor of the ZIPPML (ZINBPML) model and a large negative value in favor of the PPML (NBPML) model. See Vuong (1989: 318).

the propensity to trade for all three groundnut products, except that it exhibits a moderate volume-promoting effect for edible groundnuts. This finding is consistent with the HMR results. A larger European income increases Africa's propensity to export edible groundnuts and groundnut oil but decreases the trade volume of edible groundnuts, indicating the inferior good attribute of African edible groundnuts as in the HMR approach. A more abundant African supply enhances the intensive margins for all groundnut products, and promotes trade in edible groundnuts and groundnut oil on the extensive margins. The effect of distance ranges from positive and statistically significant to negative and statistically significant, which is unexpected in a gravity equation analysis and hard to rationalize. The lower bound of the distance effect, -6.8 in terms of elasticity, is close to the lower bound reported in Hummels (2001).

A common language has a controversial negative effect on shelled groundnuts: However, this controversy is reconciled if the interest is in the role of common language on the total trade value in all three products: the Africa-EU trade value in the sector of groundnut oil is nearly five times larger than the sector of shelled groundnuts on average, so the net effect of common language on the total trade value remains positive. The variable may confound the change in the trade composition and the trade facilitating aspects of a common language.

Next, we summarize the estimated trade effects of the MRL set by the EU. Although the ZINBPML model is slightly preferred over the HMR model based on the model diagnostics, we make use of the results in both models to summarize the trade effects of EU MRLs on African groundnut exports, which are shown in Table 6.

Table 6. The impact of the EU MRL on groundnut exports from Africa

		Edible groundnut	Shelled groundnut	Groundnut oil
HMR	Extensive margin	-0.165	-0.030	0.759
	Existing firms' margin	-0.408	0.031	1.006
	New firms' margin	-0.123	-0.013	0.287
ZINBPML	Extensive margin	-0.504	-0.139	2.090
	Intensive margin	-0.697*	0.248	1.034

Note: * denotes 10 per cent significance level.

Table 6 shows that the trade effects of EU MRLs on African groundnut exports are insignificant among the two preferred models and across three groundnut products, with one exception where the MRL seems to have promoted African exports of edible groundnuts. With this estimated elasticity of -0.697, we further simulate how much would the average trade level be for 2002-2006 if the EU harmonization in MRLs didn't occur. The result shows that Africa's export revenue in the sector edible groundnuts would be lower by USD 224,800 if the pre-harmonized MRL policies remained. In contrast to the standards-as-barriers argument for the EU's regulations on aflatoxins, our findings suggest that the effect of the EU's MRL policy on groundnut product trade is null or at best ambiguous, and certainly not impeding. Neither the propensity to create new trade partnership nor the volume exported to the previously penetrated destinations is found to be significantly influenced by the MRL in most cases.

The positive distance effects obtained in some of the HMR and ZINBPML results were unexpected. This counter-intuitive effect suggests that geographic distance might not be a good proxy for the transportation cost in Africa-EU groundnut trade. We investigated alternative specifications with interaction terms with other transaction cost variables. The problem was attenuated but did not disappear. Other variable costs such as the distance by sea and/or infrastructure facilities should be considered in further research.

In addition, we conduct several robustness checks. We address the potential endogeneity of the African supply variable, which is constructed as each African country's total exports to the rest of the world. The simultaneity of trade and output determination is a common problem in the applied trade literature. Several fixes have been recommended. Harrigan (1994) suggests using factor endowments as the instrumental variables for the output, and estimate the model by two-stage Least Squares. However, our application is so disaggregated that it would be difficult to find a valid factor endowment instrument. Another remedy is simply to constrain the coefficient of the supply to be one, or in other words let the share of exports be the dependent variable. The disadvantage of this fix is that we would not able to infer how important the domestic capacity is to the export potential of Africa. The approach we take to address the endogeneity is to construct an alternative African supply proxy from the FAOSTAT database. The database provides food supply series for a wide range of agricultural commodities and countries. For each of the nine African countries, we extract 'groundnut oil,' 'groundnuts (in shell equivalence),' and 'groundnuts (shelled equivalence)' as the alternative supply series for groundnut oil, shelled groundnuts, and edible groundnuts respectively. This alternative African supply is considered exogenous to the bilateral trade flows. As a first-pass, we use the FAOSTAT supply proxy as an instrumental variable and find that the Durbin-Wu-Hausman test fails to reject the exogeneity of the total export in the trun-OLS results. In addition, we replace total export with this alternative and re-estimate all of the models.[17] The ZINBPML model remains the most preferable one among four pseudo maximum likelihood estimators. Within the two preferred

[17] The associated results are available from authors upon request.

models, HMR and ZINBPML,[18] all trade effects of MRLs are insignificant except for one from ZINBPML, suggesting MRL marginally decrease Africa's propensity to export groundnut oil, with a significance level of 10 per cent.

Conclusion

As traditional trade barriers such as tariffs and quotas have been declining over time, there has been a concurrent upward trend in the adoption of various food safety standards. Food safety standards are driven by human health and/or environmental concerns, and generally grounded in the risk assessment of specific contaminants in food and feed. Since 1961, the Codex Alimentarius Commission jointly formed by FAO and WHO has been promoting international food safety standards that can serve as 'an international reference point.' However, many countries have not adopted these non-binding international standards, but rather have set food safety standards for a wider range of commodities and at a much tighter level than what Codex recommends, which consequently brings the possibility of a protectionist motive. This motive does not directly exist in the EU for groundnuts because they are not produced in the EU.

Our study investigates the 2002 EU's harmonization and tightening of the MRL on aflatoxin contaminants and its impact on groundnut product exports from Africa. We use a state-of-the-art toolkit for gravity equation approaches to investigate the trade effects of these EU's MRL policies on African groundnut exporters. The contribution of our analysis to the literature is triple. First of all, unlike previous econometric analyses of EU aflatoxin policies, our results suggest that the harmonization and tightening of aflatoxin regulations within the

[18] For the sector of groundnut oil, the second step of the HMR model suffers from convergence problems. Hence, the impact of MRLs on the trade volumes of groundnut oil is inferred from the ZINBPML model only.

EU has no significant effect on African groundnut exports, either in terms of the trade volumes, or the propensity to trade. This empirical result challenges the established view that a stricter food safety standard would act like a barrier to trade.

Our preferred rationalization of this lack of significant effect of the MRL policy is that the EU food safety policy is non binding for African groundnut exporters because their export potential is mostly constrained by their domestic capacity, such as farming and storage practice, and/or other trade costs before the border as strongly suggested by our second finding. We find that domestic groundnut supply conditions in Africa appear to be a binding constraint for its groundnut exports across all methods of estimation. This finding implies that it is the domestic issue rather than the accessibility to the EU market that constrains Africa's export potential. Addressing Africa's under-trading problem from a development viewpoint might be more helpful than merely improving international accessibility for African traders (Bouët, Mishra, and Roy, 2008; Rios and Jaffee, 2008). Last, our application sheds light on the performance of different estimation strategies for the gravity equation model, especially in the context of numerous zero observations.

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Appendix

Margins in the HMR model

In general, the selection equation determining firms' self-selection to export is specified as $\Pr(Y > 0) = \Phi(X\gamma)$.

The outcome equation generating the trade levels conditional on trade taking place is specified as

$$E(\ln Y \mid Y>0)=\sum_k x_k\beta_k+\ln\{\exp[\delta(z+IMR)]-1\}+\eta IMR,$$

where $\delta>0$ is a function of the shape parameter in the Pareto distribution governing firms' productivity, the constant elasticity of substitution, and the estimated variance in the selection equation;[19] $z=x'\cdot\hat{\gamma}$ is the linear prediction in the selection equation; $IMR=\phi(z)/\Phi(z)$ is the Inverse Mill's Ratio as in Heckman (1979). The second term on the right hand side captures the trade effect of newly entered firms; and the third term on the right hand side corrects for the sample selection bias. Because we find no evidence of significant sample selection errors across all three products (see Table 3), we assume $\eta=0$ thereafter.

Applying the rules of conditional expectations, we have

$$E(Y)=E(Y\mid Y>0)\cdot\Pr(Y>0)+E(Y\mid Y=0)\cdot\Pr(Y=0)=E(Y\mid Y>0)\cdot\Pr(Y>0).$$

Taking the logarithm of the above equation, and then taking the derivative with respect to an exogenous variable, x_k for instance, we have

$$\frac{\partial\ln E(Y)}{\partial x_k}=\underbrace{\frac{\partial\ln E(Y\mid Y>0)}{\partial x_k}}_{\text{intensive margin}}+\underbrace{\frac{\partial\ln\Pr(Y>0)}{\partial x_k}}_{\text{extensive margin}}.$$

The above equation states that the overall marginal effect can be decomposed into an *intensive margin* $\frac{\partial\ln E(Y\mid Y>0)}{\partial x_k}$, that is, the intensification of existing trade flows, and an *extensive margin* $\frac{\partial\ln\Pr(Y>0)}{\partial x_k}$, that is, the creation of new trade. Note that the extensive margin can be readily computed from the estimates in the selection equations.

As Hoffman and Kassouf (2005) shows, $\frac{\partial\ln E(Y\mid Y>0)}{\partial x_k}=\frac{\partial E(\ln Y\mid Y>0)}{\partial x_k}$ holds under some regular conditions.[20] Therefore, the intensive margin can be computed as

$$\underbrace{\frac{\partial\ln E(Y\mid Y>0)}{\partial x_k}}_{\text{intensive margin}}=\frac{\partial E(\ln Y\mid Y>0)}{\partial x_k}=\underbrace{\hat{\beta}_k}_{\substack{\text{existing}\\ \text{firms}\\ \text{margin}}}+\underbrace{\frac{\exp[\hat{\delta}(z+IMR)](\frac{\phi'(z)}{\Phi(z)}-IMR^2+1)\hat{\delta}}{\exp[\hat{\delta}(z+IMR)]-1}\hat{\gamma}_k}_{\text{new firms margin}},$$

where $\phi'(z)=-\frac{z}{\sqrt{2\pi}}\exp(-0.5z^2)$ is the derivative of the standard normal density function.

The above equation states that the intensive margin can be further decomposed into the *existing firms' margin* and the *new firms' margin*.

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[19] Readers are referred to Equation (13) in HMR (2008) for the definition of δ.

[20] Readers are referred to Appendix B of Hoffman and Kassouf (2005) for a detailed exploration of the conditions.

Margins in the ZINBPML model

In general, the inflation equation is specified as

$$\Pr(NoTrade) = \Phi(X\delta).$$

The outcome equation is specified as

$$E(Y \mid Trade) = \exp(\sum_k x_k \psi_k).$$ [21]

Applying the rules of conditional expectations, we have

$$E(Y) = E(Y \mid Trade)\cdot \Pr(Trade) + E(Y \mid NoTrade)\cdot \Pr(NoTrade) = E(Y \mid Trade)\cdot \Pr(Trade).$$

Taking the logarithm to the above equation, and then taking the derivative with respect to an exogenous variable, x_k for instance, we have

$$\frac{\partial \ln E(Y)}{\partial x_k} = \frac{\partial \ln E(Y \mid Trade)}{\partial x_k} + \frac{\partial \ln \Pr(Trade)}{\partial x_k}.$$

Replacing $\Pr(Trade)$ with 1- $\Pr(NoTrade)$, we have

$$\frac{\partial \ln E(Y)}{\partial x_k} = \underbrace{\hat{\psi}_k}_{\text{intensive margin}} + \underbrace{[-\frac{\phi(x'\hat{\delta})}{1-\Phi(x'\hat{\delta})}\cdot \hat{\delta}_k]}_{\text{extensive margin}}.$$

In the above equation, the first term on the right hand side, $\hat{\psi}_k$, is the intensive margin; the second term on the right hand side captures the extensive margin.

[21] Compared to the outcome equation in the HMR model, the outcome equation in the ZINBPML permits zero trade flows.

CHAPTER 3. DISENTANGLING THE DEAMND-ENHANCING EFFECT AND THE TRADE-COST EFFECT OF TECHINCAL MEASURES IN AGRICULTURAL TRADE AMONG OECD COUNTRIES

Abstract

Domestic technical measures such as SPS and TBTs can enhance import demand via information disclosure and quality improvement, or hamper foreign export supply via imposing sizeable compliance costs, or both. The traditional gravity equation model estimates the net effect of these measures on international trade with a loss of useful inference on separate effects. We stipulate a generalized gravity equation model to disentangle the two effects. We apply the augmented approach to agricultural trade among OECD countries in 2004. We find that technical measures in agriculture often jointly enhance import demand and hinder export supply with the net effect of promoting the propensity to trade. Further disaggregated data analysis reveals heterogeneity across sectors in terms of net effects of technical measures, despite common demand-enhancing and supply-hindering effects. These measures in the net decrease the probability of intra-OECD trade in dairy products, whereas they increase that of intra-OECD trade in cereal preparations.

Introduction

The Agreements on the Application of Sanitary and Phytosanitary (SPS) Measures and Technical Barriers to Trade (TBT) of the World Trade Organization (WTO) took effect in 1995. They allow WTO member countries to apply SPS and TBT measures to protect domestic human health, animal and plant health, and the environment. However, concerns that these measures create trade frictions and serve protectionist motives have been brought up frequently. For instance, the Philippines, in a complaint to the WTO in 2002, claimed that Australia's SPS measures on fresh fruit and vegetables had hurt its exporters unnecessarily. In 2010, Indonesia filed a WTO dispute against the United States (DS406) for imposing restrictions on cigarette additives thus affecting the production and sale of Indonesian clove cigarettes. In general, the implications of technical measures[22] on market access and welfare are more complex than traditional tax-based trade barriers measures, such as tariffs and countervailing duties, primarily because they often address market imperfections (asymmetric information, externalities). They tend to affect consumers' information set and behavior as well as producers' behavior. Thus they cannot be easily translated into a simple tax or price equivalent. Their welfare effects are fundamentally different as well. The presumption that the removal of technical measures is welfare-improving is not grounded in any economic theory, unlike for the removal of a trade tax by a small country.

From the perspective of exporters, the additional cost of complying with a stringent standard abroad could be high. Those compliance costs may include the fixed costs of upgrading the equipments and/or practice codes, gaining certificates, altering marketing strategies, etc. In addition, inspection procedures at custom points add to the variable cost of exporting. As a result, the compliance costs could significantly decrease export volumes, and drive small exporting firms out of a foreign market. This is the trade-cost effect, or the supply-inhibiting effect of technical measures, which corresponds to the conventional "standards as barriers" argument in the international development literature on market access (Otsuki,

[22] Throughout the article, we use technical measures, SPS measures, and quality standards interchangeably.

Wilson, and Sewadeh, 2001a).

On the other hand, a technical measure may enhance the demand for imports if the measure is informative (Thilmany and Barrett, 1997). In the latter case, the measure signals a higher quality of the permitted imports via information disclosure such as trade marks, labeling requirements, and detailed description of certain attributes or restricting toxic residues. The quality improvement enhances consumers' demand for imports, as well as contributes to consumers' long-run health benefits (Marette and Beghin, 2010). This is the demand-enhancing effect, or the quality improvement effect of technical measures, corresponding to the "standards as catalyst" argument in the SPS/TBT debate. (The "standards as catalyst" argument also includes the claim that stringent foreign standards could trigger exporters to upgrade their supply chain, to access higher quality markets opportunities in the long-run, e.g., Jaffee and Henson, 2005). Therefore, a technical measure can affect trade volumes and/or the propensity to trade in either direction: a tighter standard promotes trade if its demand-enhancing effect dominates its trade-cost effect; it impedes trade if its demand-enhancing effect falls short of the trade cost effect. The analytical ambiguity of the impact of technical measures on international trade calls for a more careful empirical quantification and identification of the trade effects of these measures, a task we pursue in this investigation.

Gravity equation models are widely used to estimate bilateral trade flows and their determinants such as the attributes of trading countries (such as GDP, total production) and various trade cost terms (such as tariffs, distance, colonial ties, and preferential trade agreements), including certain technical measures imposed by the importing countries. The existing results accumulated so far on trade effects of technical measures are mixed. The estimated net effects of technical measures vary across products, country groups, and to some extent estimation methods with net trade effects spanning from significantly negative to significantly positive (Li and Beghin, 2010). For example, Otsuki, Wilson, and Sewadeh (2001a) predicted that 2002 EU harmonization of aflatoxin residue standards would reduce groundnut exports from Africa. This prediction could not be confirmed by Xiong and Beghin (2011) in an ex-post panel analysis. Jaffee and Masakure (2005) report that Kenyan fresh vegetable exporters benefited from the proliferation of food safety standards in Europe by successfully updating their supply chains. Anders and Caswell (2009) find that Hazard Analysis Critical Control Points (HACCP) reduces American's seafood imports from large exporting countries. Disdier, Fontagné, and Mimouni (2008) show that agricultural exporters from the South are more likely to be hurt by rising TBTs and technical measures than their competitors from the OECD countries but that they measure can enhance trade in some sectors among OECD partners, while hindering trade or having no net trade effects in other sectors. Disentangling the separate impacts of technical measures on import demand and export supply would allow a cogent rationalization of these various outcomes. However, studies toward the identification of the two effects are rare to date. (As a case study on Japanese cut flowers, Yue and Lan (2009) show that estimates of the trade effect of SPS are biased when the induced quality changes are not considered).

We undertake to separately identify these supply and demand effects. This is a useful pursuit. First, the disentanglement of consumers' and producers' responses to an informative standard helps determine if the standard is driven by public awareness or potential protectionism. (Fugazza and Maur (2008) demonstrate the importance of modeling both the demand and supply-shift effects of technical measures in policy analysis using CGE models). In case consumers are found to be insensitive to the quality improvement induced by a higher standard, the new policy should be subject to further scrutiny for possible protectionism. For instance, the absence of direct demand-enhancing effect could also be consistent with policies addressing long-term deleterious health or environmental effects valued by society but overlooked by consumers of the good affected by the technical measure (e.g., Peterson and Orden 2008). Second, the disentangled approach provides grounds for better policy recommendation both for domestic consumers and development assistance to exporters in the South, potentially handicapped by technical measures. For example, the fairly common finding of negligible net trade effect of technical measures (e.g., Xiong and Beghin, 2011) may dissimulate a potential demand-enhancing effect beneficial to consumers and mostly offset by exporters' inability to comply with the measures. The latter could lead to international assistance programs to exporters in the South.

Moreover, the disentanglement of the effects of SPS measures on consumers and producers makes possible the welfare evaluation of a policy change. Disdier and Marette (2010) use an analytical framework to link the mercantilist aspects and welfare aspects of non-tariff measures and find that although antibiotic residue limits reduce crustaceans imports in US, EU, Canada, and Japan, they boost both domestic and international welfare. Therefore, a proper disentangling strategy would allow exploring how a change in SPS polices affects different agents in international trade. Identifying the two separate effects could also lead to better policy design by the social planner, especially in presence of externalities associated with trade. An optimum measure can be designed with proper knowledge of its impact on consumers.

We propose an econometric approach to disentangle the demand-enhancing effect and the trade-cost effect of any standard and apply the model to examine the impact of technical measures on agricultural trade among OECD countries in 2004. The two effects can be told apart based on two simple but essential facts. First, the maximum of the domestic standards and the foreign standards affects consumers' demand for imports: the domestic standards serve as the quality signal if the home country adopts stricter regulations than the exporting country; the foreign standards serve as the quality signal if higher standards are applied abroad. However, the difference in standards between the trading countries influences the trade costs of exporting firms: a firm already meeting a stringent regulation in its home market can meet the standards in the country of destination easily or at no additional cost. For instance, seafood exporters from Canada are arguably better equipped to meet U.S. HACCP regulations than seafood exporters from Thailand because HACCP procedures are common in Canada.

We apply the model to investigate agricultural trade among OECD countries in 2004 and significantly refine the findings of Disdier, Fontagné, and Mimouni (2008). We find that technical measures facilitate intra-OECD agricultural trade, for those measures enhance consumers' demand for imports more than they handicap exporters' supply of exports. In a further disaggregated analysis of technical measures imposed on cereal preparations primarily targeting mycotoxins, we find that these measures tend to in the net to induce additional intra-OECD trade in cereal products. In contrast, technical measures affecting dairy products tend to decrease the trade among OECD countries in their net effect. Demand enhancing effects are found in both of these sectors.

In what follows, we provide a conceptual model leading to a specification disentangling the two effects of technical measures. Then we apply the model to empirically examine the impact of technical measures on agricultural trade among OECD countries in 2004. Section 4 concludes the analysis and discusses possible extensions.

The Modeling Approach

Our analytical framework characterizes the separate impact of technical measures on the demand for imports and the supply of exports. In equilibrium, a generalized gravity equation model emerges and provides a specification to be estimated which preserves the identification of the separate impacts on domestic consumers and foreign exporters. Welfare implications are also discussed.

The Import Demand

The goods available in the economy are differentiated by sectors and by country of origins (Armington, 1969). For example, "Japanese apples" and "New Zealand apples" are two distinct goods in the composite sector "apples." There are S sectors. There are I countries trading or potentially trading with one another. Country j has N_j identical consumers deriving utility from market consumption and long-run health (or the environment). The implementation of a standard affects both utility channels. The standard affects individual consumption level by conveying a quality signal to consumers. In addition, there might be certain long-run health benefits (individual and collective ones) associated with the standard but overlooked by individual consumers. For example, standards restricting antibiotic use in food provide quality enhancements perceived by consumers and collective health benefits from reduced antibiotic resistance likely to be external considerations for many individuals (Beghin and Marette, 2009; Disdier and Marette, 2010). Similar external environmental effects are often linked to the volume of trade, such as invasions by exotic pests.

To accommodate the above features, we use the Constant Elasticity of Substitution (CES) preferences to characterize consumers' utility derived with market consumption and we assume that the health or environmental benefit is additively separable from the market consumption utility. Specifically, the representative consumer in country j solves the following optimization problem:

$$\text{(1a)} \quad \max_{q_{sij}} U_j = [\sum_s \sum_i (\delta_{sij} q_{sij})^{\frac{\varepsilon-1}{\varepsilon}}]^{\frac{\varepsilon}{\varepsilon-1}} - \sum_i \sum_s \kappa(\delta_{sij}) Q_{sij}$$

$$\text{(1b)} \quad s.t. \; \sum_s \sum_i P_{sij} q_{sij} = y_j \,,$$

where δ_{sij} is the quality preference parameter of the representative consumer in country j for good s produced by country i; q_{sij} is the consumer's quantity demanded for good s produced by the country i; $\kappa(\cdot)$ is a decreasing function mapping the quality of the good to the per-unit hazard associated with the import; Q_{sij}, exogenous to individual consumers, is country j's aggregate demand for good s sourced in country i; ε is the constant elasticity of substitution; P_{sij} is the price of good s produced in country i and sold in country j; y_j is the per-capital income in country j. Solving the representative consumer's problem (1) yields the following individual demand:

$$\text{(2)} \qquad q_{sij}^d = \frac{\delta_{sij}^{\varepsilon-1} P_{sij}^{-\varepsilon}}{\Pi_j} y_j \,,$$

where $\Pi_j = \sum_s \sum_i \delta_{sij}^{\varepsilon-1} P_{sij}^{1-\varepsilon}$ is the consumer price index in country j. Note that the long-run health benefit doesn't affect the solution at all since the external effect is assumed separable for tractability. Country j' aggregate demand for good s produced by the country i, in value terms, is then

(3) $$V_{sij}^{d} \equiv P_{sij} \cdot Q_{sij}^{d} = P_{sij} \cdot N_{j} \cdot q_{sij}^{d} = \frac{\delta_{sij}^{\varepsilon-1} P_{sij}^{1-\varepsilon}}{\Pi_{j}} y_{j} N_{j} = \frac{\delta_{sij}^{\varepsilon-1} P_{sij}^{1-\varepsilon}}{\Pi_{j}} Y_{j},$$

where Y_j is country j's national income. Note that the above import demand is positively related to the income level and the consumers' quality evaluation of the good, but negatively related to the price of the good as long as $\varepsilon > 1$.

The information disclosed by the technical measures, among many factors, can alter consumers' quality evaluation of the concerned good. We parameterize δ_{sij} as

(4) $$\delta_{sij} = \delta_{s0} \exp(\beta \max\{SPS_{si}, SPS_{sj}\}),$$

where δ_{s0} is consumers' preference for good s in absence of technical regulations;[23] β, is a non-negative parameter to be estimated that captures the degree to which consumers respond to the technical information disclosure; SPS_{si} and SPS_{sj} are the stringency of technical measures imposed on sector s in country i and j. Hence, the term $\exp(\beta \max\{SPS_{si}, SPS_{sj}\})$ characterizes the demand-enhancing effect, or the quality improvement effect of technical measures. Notably, Equation (4) assumes full compliance of all firms: a firm must meet its domestic standards in the first place, and it has to improve the quality of its exports to meet the foreign standards if selling to a destination where stricter standards apply. In the latter case, consumers in the destination country care about the higher domestic quality signal. However, if a foreign firm has a quality exceeding the importing country's quality requirement, then consumers in the latter country react to the stricter quality requirements adopted by the

[23] All other factors affecting consumers' quality perception or evaluation are subsumed in δ_{s0}.

exporting country.[24]

The Export Supply

We assume a representative producer for each sector in each country. The products sold by this representative producer at different destinations are imperfect substitutes because the producer has to further modify the products to meet the local quality requirements in each destination country (re-packaging, re-labeling, etc). For example, U.S. apples to be sold in Japan are not exactly the same as U.S apples consumed domestically (Calvin, Krissoff, and Foster 2008). We further assume the representative producer of good s in country i is endowed with a production capacity Q_{si} and a Constant Elasticity of Transformation (CET) technology (Geraci and Prewo 1982; Bergstrand 1985). The CET technology allows the exporter to transform products prepared for different destinations. The problem for the representative producer is to decide which countries to export to and how much to export to each foreign market. Let Ω_{si} be the set of destinations the representative producer of good s in country i decides to serve.[25] The producer solves the following problem

(5a) $$\max_{\{Q_{sij}\}_{j\in\Omega_{si}}} \sum_{j\in\Omega_{si}} P_{sij}Q_{sij}$$

(5b) $$s.t.\ \ [\sum_{j\in\Omega i}(\tau_{sij}Q_{sij})^{\frac{\eta-1}{\eta}}]^{\frac{\eta}{\eta-1}} = Q_{si},$$

where $\eta < 0$ is the CET between exports prepared for different destinations (a large η in

[24] Consumers are assumed to be cognizant of both domestic and foreign quality signals implied by the measures. This is consistent with a label stating that quality exceeds the standard in the destination market.
[25] For the purpose of tractability, we do not explicitly model the endogenous choice of Ω_{si}. However, in the empirical part, we partially account for countries' decision to export or not by using the Heckman sample selection model. Interested readers are referred to Helpman, Melitz, and Rubinstein (2008) for a detailed characterization of firms' exporting behavior.

absolute value corresponds to easy transformation); $\tau_{sij}>1$ is the "iceberg melting" trade cost term: τ_{sij} units of good s have be to shipped out of country i in order for one unit to arrive in country j. The solution to (5) yields the following export supply functions in value terms:

$$V_{sij}^{s} \equiv P_{sij} \cdot Q_{sij}^{s} = \frac{Q_{si}\tau_{sij}^{\eta-1}}{\Psi_{si}P_{sij}^{\eta-1}}, \tag{6}$$

where $\Psi_{si} = [\sum_{j\in\Omega_{si}} \tau_{sij}^{\eta-1} P_{sij}^{1-\eta}]^{\frac{\eta}{\eta-1}}$ is the producer price index for sector s in country i reflecting the cost of exporting to all possible destinations. Equation (6) suggests that the supply of exports is positively related to the production capacity of the exporting country and the price of the goods, but negatively related to trade cost terms.

With the empirical investigation in mind, and as standard practice in gravity equation models, we parameterize τ_{sij} as

$$\begin{aligned}\tau_{sij} &= (1+tar_{sij})(1+dist_{ij})^{b_d}\exp(-b_p NTB_{sj})\exp(-b_b Bord_{ij}) \\ &\cdot\exp(-b_c Col_{ij})\exp(\gamma\max\{SPS_{sj}-SPS_{si},0\}),\end{aligned} \tag{7}$$

where tar_{sij} is the bilateral tariff rates in sector s; $dist_{ij}$ is the distance between country i and j; NTB_{sj} represents the protectionist non tariff barrier (other than technical measures) imposed in sector s by country j;[26] $Bord_{ij}$ is a common border dummy variable that equals one if the trading partners share a common border; Col_{ij} is a colonial dummy variable that equals one if the two countries had a colonial relationship in history; γ, b_d, b_b, b_c, all presumably positive, are parameters to be estimated.

[26] These protectionist non-tariff barriers differ from the technical measures or SPS measures in that they do not constitute quality signals thus presumably impede trade by suppressing the supply of exports. See further discussion in Section 3.

The new source of trade cost in (7) is $\max\{SPS_{sj} - SPS_{si}, 0\}$, which characterizes the trade cost due to the difference in technical measures between trading countries. The trade cost term implies that exporting firms have to overcome additional costs (e.g., expenditure on additional equipments to improve quality, further processing, obtaining necessary certificates, etc.) if selling to a destination where a stricter standard applies relative to their home country's standard. Czubala, Shepherd, and Wilson (2007) find that the harmonized or shared standards are less trade-impeding and sometimes trade-promoting. Our formulation of the trade cost effect accommodates such harmonized or shared standards ($SPS_{sj} = SPS_{si}$). For instance, intra-EU trade is presumably less impeded or even promoted by EU's technical measures because of their harmonization within the community.

The Equilibrium

In equilibrium, the import demand equals the export supply in each sector and for each country pair. By imposing the market clear condition, $V_{sij}^{d} = V_{sij}^{s}$, we can solve for the equilibrium trade value, V_{sij}, and the equilibrium price, P_{sij}, in sector s for the exporting country i and the importing country j. Specifically, solving (3) and (6) yields

(8a) $$P_{sij} = \left(\frac{Y_j}{\Pi_j}\right)^{\frac{1}{\varepsilon-\eta}} \left(\frac{\Psi_{si}}{Q_{si}}\right)^{\frac{1}{\varepsilon-\eta}} \delta_{sij}^{\frac{\varepsilon-1}{\varepsilon-\eta}} \tau_{sij}^{\frac{1-\eta}{\varepsilon-\eta}},$$

(8b) $$V_{sij} = \left(\frac{Y_j}{\Pi_j}\right)^{\frac{1-\eta}{\varepsilon-\eta}} \left(\frac{Q_{si}}{\Psi_{si}}\right)^{\frac{\varepsilon-1}{\varepsilon-\eta}} \left(\frac{\delta_{sij}}{\tau_{sij}}\right)^{\frac{(\varepsilon-1)(1-\eta)}{\varepsilon-\eta}}.$$

It can be noted from (8a) that the equilibrium price is increasing in the importing country's income level, Y_j, the quality of the imports, δ_{sij}, and the trade cost between the two countries,

τ_{sij}; but it is decreasing in the exporting country's total supply capacity, Q_{si}. Equation (8b) shows that the bilateral trade flow (in value) is increasing in the importing country's income level, Y_j, the exporting country's capacity, Q_{si}, and the quality of the imports, δ_{sij}; but it is decreasing in the trade cost between the two countries, τ_{sij}. Substituting (4) and (7) into (8b), and taking logarithms lead to following characterization of equilibrium bilateral trade flows

$$\begin{aligned}\ln(V_{sij}) &= \phi Y_j - \phi\Pi_j + (1-\phi)Q_{si} - (1-\phi)\Psi_{si} - \theta\ln(1+tar_{sij}) - \theta b_p NTB_{sj} - \theta b_d \ln(1+dist_{ij}) \\ &+ \theta b_b Bord_{ij} + \theta b_c Col_{ij} - \theta\gamma\max\{SPS_{sj} - SPS_{si}, 0\} + \theta\beta\max\{SPS_{sj}, SPS_{si}\},\end{aligned} \tag{9}$$

where $\phi = (1-\eta)/(\varepsilon-\eta)$ and $\theta = (\varepsilon-1)(1-\eta)/(\varepsilon-\eta)$.

Equation (9) forms a generalized gravity equation model in which the demand-enhancing effect and the trade cost effect of SPS measures are identified separately. The most stringent set of standards between exporting and importing countries affects consumers' valuation of the concerned good by signaling the highest quality between the two. On the other hand, stringency differentials between the trading partners influence trade costs and export supply: a firm already meeting stringent home regulations can meet the standards in the destination country at negligible additional cost. The proposed model makes explicit how underlying demand and supply components of bilateral trade react to technical measures. Meanwhile, the model retains the parsimony and spirit of the gravity equation approach.

Besides noting the disentangling the two effects of SPS/TBT measures, our specification leads to several remarks. First, the inclusion of tariffs as a determinant of trade remains essential to identify the model structure as in many gravity applications. Equation (9) shows that the trade effects of all other trade costs combine the price effect of tariffs (parameter θ) to their specific impacts on unit cost of each other trade cost as shown in equation (7). Secondly, the estimated trade effects of technical measures may suffer from omitted variable bias if the technical measures adopted by the exporting countries are ignored. Equation (9) shows that trade flows are independent of the standards applied by the country of origin, SPS_{si}, if and only if $SPS_{si} = 0$, that is, the exporting country has no technical measures of its own. Last, the recovered elasticities of substitution in traditional gravity equation models analyzing technical measures should be interpreted with caution. The elasticity recovered here, $\theta = (\varepsilon - 1)(1-\eta)/(\varepsilon - \eta)$, includes both CES and CET parameters and provides information on consumers' taste patterns, as well as exporters' ability to transform products across destinations.

At last, we discuss some of the welfare implications of a new standard on good s by the importing country, specifically on its consumers' and foreign exporters' welfare. To characterize the welfare effect for domestic consumers, we substitute (2) and (8a) into (1a) to get the indirect utility function for country j as follows:

$$(10) \qquad W_j = A_j (\sum_i \sum_s B_{si} \delta_{sij}^{\theta} \tau_{sij}^{-\theta})^{\frac{\varepsilon}{\varepsilon - 1}} - A_j \sum_i \sum_s B_{si} \kappa(\delta_{sij}) \delta_{sij}^{-\eta(1-\phi)} \tau_{sij}^{-\varepsilon\phi} ,$$

where $A_j = (\frac{Y_j}{\Pi_j})^{-\frac{\eta}{\varepsilon - \eta}}$ and $B_{si} = (\frac{Q_{si}}{\Psi_{si}})^{\frac{\varepsilon}{\varepsilon - \eta}}$. The first term on the right hand side of (10) captures in the surplus associated with market consumption, while the second term characterizes the consumers' welfare implications on long-run health or other external effect. [27] For simplicity sake, we assume for a moment that the new standard adopted by country j only affects exporter i. (All other trading partners already have the same or the equivalent

[27] We leave out the impact of domestic standards on domestic producers. Presumably, the effect can be either positive, if the domestic producers successfully comply with the regulations, or negative, if the associated compliance costs turn out significant.

standards in place). The first term in (10) captures the consumer surplus effects. The quality improvement associated with the new regulation increases δ_{sij}, which benefits domestic consumers and increases their willingness to pay for q_{sij}. On the other hand, trade cost rises with the new stringency faced by the exporter; the price of the good increases and welfare is reduced. Consequently, the net effect on the consumer surplus from consuming good s is presumably ambiguous. Secondly, the negative external effect shown in the second term of (10) is reduced via lower morbidity or reduced invasion rates $\kappa(\delta_{sij})$, although trade expansion could exacerbate these external effects.

The total welfare effect on the consumer is presumably ambiguous and is unlikely to be just determined by effect on the volume of trade as often assumed in gravity analyses of NTMs. The quantification of the demand-enhancing effect and the impact on potential externalities is essential: the more information standards convey to consumers, and/or the more scientific evidence underlies the regulations, the weaker the presumption of sheer protectionism and welfare losses.

Country j's new regulation affects foreign exporters' profits. By assumption, exporters from country i face additional cost to continue selling in country j. By substituting (6) and (8a) into (5a), we derive the following profit function for the representative exporter i in sector s:

$$(11) \qquad \pi_{si} = \sum_{j\in\Omega_{si}} V_{sij}^{s} = B_{si}^{\frac{\varepsilon}{\varepsilon-1}} \sum_{j\in\Omega_{si}} A_j^{\frac{1-\eta}{-\eta}} \delta_{sij}^{\theta} \tau_{sij}^{-\theta} .$$

It can be noted from (11) that the profit is increasing in the perceived quality of the imports, δ_{sij}, in country j but decreasing in the trade costs, τ_{sij} to meet the new standard.

Hence, the importing country's new regulation has two direct offsetting effects on the profit of foreign exporters (higher willingness to pay in the importing country but higher trade cost to sell there). The relative size of these effects determines the direct impact of the new standard on profits. [28]

In summary, from the above discussion of equations (10) and (11), it is clear that technical measures and their stringency have complicate welfare implications requiring the disentanglement of their separate effects on import demand and export supply as also emphasized by Disdier and Marette (2010), and Beghin et al. (2011).

An Empirical Application

In this section, we apply the proposed model to examine the impact of technical measures on agricultural and food trade among OECD member countries using data for the year 2004. The data come from Disdier, Fontagné, and Mimouni (2008) and COMTRADE. As in Disdier, Fontagné, and Mimouni (2008), we run a regression based on pooled data for all sectors and then separate regressions based on sectoral data with a detailed investigation of trade in dairy and cereal preparations. The dataset is rich but unfortunately is a pure cross-section without time variation. This constraint means that we can only identify the effects of variables that are not co-linear in absence of time variation in the data. Accordingly, we re-write (9) as

$$\text{(12)} \quad \begin{aligned} \ln(V_{sij}) = &-\theta \ln(1+tar_{sij}) - \theta b_p NTB_{sj} - \theta b_d \ln(1+dist_{ij}) + \theta b_b Bord_{ij} + \theta b_c Col_{ij} \\ &- \theta\gamma \max\{SPS_{sj} - SPS_{si}, 0\} + \theta\beta \max\{SPS_{sj}, SPS_{si}\} + fe_j + fe_{si}, \end{aligned}$$

where fe_j is the fixed effect, or the multilateral resistance term (Anderson and van Wincoop

[28] Additionally, the new standard affects exporters' profitability in other destinations by altering the relative prices across foreign markets. We abstract from such indirect trade diversion effect in our discussion.

2003) of the importing country j; fe_{si} is the fixed effect in sector s in the exporting country i. Note that importers' fixed effects absorb the impact of the price indexes, Π_j and incomes Y_j, in the importing countries; and that sector-specific exporters' fixed effects subsume the impact of the price indexes, Ψ_{si}, and the production capacity, Q_{sit}, in the exporting countries. Admittedly, the lack of time variation in the across-sectional analysis prevents us from identifying ε and η separately but we can still identify the separate shifts resulting from demand enhancing effects and export supply cost effects of technical measures affecting trade.

Data and Empirical Strategy

The data set largely draws upon Disdier, Fontagné, and Mimouni (2008). Information on non tariff measures (NTMs) in 2004 is retrieved from the Trade Analysis Information System (TRAINS). Various measures imposed by the importing countries are recorded at each HS-6 product level. According to the United Nations Conference on Trade and Development (UNCTAD), a NTM measure can be sorted into the following seven categories: (a) para-tariff measures, (b) price control measures, (c) finance measures, (d) automatic licensing measures, (e) quantity control measures, (f) monopolistic measures, and (g) technical measures. Among the seven categories, (a) (b) (e) and (f) are protectionist by design as they decrease allocative efficiency, so we pool these four categories together and call them "protectionist NTBs." Category (g) contains the technical measures we are interested in. We restrict our attention to intra-OECD trade because notifications by non-OECD countries are often not up to date and incomplete. One would estimate the impact of notification behavior rather than the impact of actually implemented policies if including NTMs notifications by non-OECD countries.

The intra-OECD agricultural trade and tariff data are collected from the “Base pour l’Analyse du Commerce International” (BACI), of Centre d’Etudes Prospectives et d’Informations Internationales (CEPII), and augmented with COMTRADE-WITS. They are aggregated at the HS-4 level. Within each HS-4 category and for each country, a *frequency index* proxy-ing the stringency of technical measures is constructed as the total number of “technical measure” notifications within that HS-4 category over the total number of HS-6 level products within that HS-4 category. For example, New Zealand issued a total of 80 technical measures (measures applied to different HS-6 products are considered distinct even if the requirements are the same) under the HS-4 category “fruits, nuts and other edible parts of plants” in 2004. This particular HS-4 category contains 12 HS-6 products. Hence, New Zealand’s frequency index of technical measures applied to “fruits, nuts and other edible parts of plants” is 6.67. A frequency index representing the intensity of the use of protectionist NTBs (other than the technical measures) is constructed in a similar manner. Other trade cost terms, including bilateral distance, common border dummy variable, common language dummy variable, and colonial tie dummy variable, are sourced from CEPII.[29]

Our estimation strategy is to rely on the Heckman sample selection model. The Heckman sample selection model has three empirical advantages. First of all, it accounts for countries’ self-selection to not export by including a selection equation. This selection could be caused by the inability to overcome certain fixed costs of trade. Thus, the Heckman

[29] Some tariff and trade data are missing in Disdier, Fontagné and Mimouni (2008). We complement the data with COMTRADE. Nevertheless, the bilateral tariff series is still incomplete. We drop those observations with missing tariffs. As a robustness check, we replace with missing tariffs with the sample averages at importer level. The results are qualitatively unchanged.

sample selection model is in line with the micro-foundation of gravity equation models as proposed by Helpman, Melitz, and Rubinstein (2008) and addresses the problem with frequent zero outcomes. (Another estimator capable of accommodating zeros numerically is the Poisson Pseudo Maximum Likelihood (PPML) estimator advocated by Silva and Tenreyro 2006. However, Martin and Pham (2008) show that PPML can lead to biased estimates when zeros are frequent). Second, the Heckman sample selection model allows exploring both the intensive and the extensive margins to trade. Technical measures can either affect exporter's trade volumes via increasing the variable cost of exporting, or their propensity to trade via adding to the fixed cost of trade, or both. It is worthwhile to investigate both margins and determine how the technical measures affect the related industry. Lastly, the Heckman sample selection model corrects for the sample selection bias inherent in traditional Least-Square estimators. Specifically, the Heckman sample selection model, based on (12), is

$$\text{(13a)}\quad \begin{aligned}\ln(V_{sij} \mid V_{sij} > 0) = &-\theta \ln(1+tar_{sij}) - \theta b_d \ln(1+dist_{ij}) + \theta b_p NTB_{sj} + \theta b_b Bord_{ij} + \theta b_c Col_{ij} \\ &- \theta\gamma \max\{SPS_{sj} - SPS_{si}, 0\} + \theta\beta \max\{SPS_{sj}, SPS_{si}\} + fe_j + fe_{si} + \varepsilon_{sij},\end{aligned}$$

$$\text{(13b)}\quad \begin{aligned}V^*_{sij} = &-\theta^* \ln(1+tar_{sij}) - \theta^* b^*_d \ln(1+dist_{ij}) + \theta^* b^*_p NTB_{sj} + \theta^* b^*_b Bord_{ij} + \theta^* b^*_c Col_{ij} \\ &+ \theta^* b^*_l Lang_{ij} - \theta^* \gamma^* \max\{SPS_{sj} - SPS_{si}, 0\} + \theta^* \beta^* \max\{SPS_{sj}, SPS_{si}\} + fe^*_j + fe^*_{si} + \upsilon_{sij},\end{aligned}$$

where $V_{sij} > 0$ if and only if $V^*_{sij} > 0$. Equation (13a) is the outcome equation that explains the trade volume conditional on trade taking place. If the sample selection bias is present, the idiosyncratic term is correlated with covariates in (13a). Equation (13b) is essentially a Probit model in which the outcome is one if two countries trade with each other, and zero otherwise. We can estimate (13a) and (13b) jointly either via the maximum likelihood approach, assuming that the idiosyncratic terms are bivariate normal with correlation ρ, or via a two-step procedure.[30] For identification purpose, the Heckman sample selection mode often uses an exclusion restriction. A variable in the selection equation is excluded from the outcome equation. In our context, a variable that affects the fixed cost of trade but not the variable cost of trade would qualify. However, it is often difficult to find such a variable. Helpman, Melitz, and Rubinstein (2008) use "days and procedures needed to start a business" for this purpose, but they also use the common religion dummy variable as an alternative due to the limit data on the above-mentioned variable. We choose the common language dummy variable as the exclude variable in our application.[31]

In the next subsection, we first examine the impact of technical measures on intra-OECD agricultural trade in general. To this end, we pool different agricultural sectors together and fit the Heckman sample selection model (13a)-(13b). We then analyze each sector (at HS-2 level) separately to see how different products have been affected by technical measure.

Results Discussion

The estimation results for the intra-OECD agricultural trade in 2004 are reported in table 1. We first discuss the estimates in the outcome equation to see how different factors determine the trade volumes conditional on countries trading with one another, and then we turn to the estimates in the selection equation to explore what affects the propensity to trade. As shown in the second column of table 1, the technical measures adopted by OECD countries enhance consumers' demand for imports significantly, suggesting that the OECD

[30] In the next subsection, we report the results from the two-step procedure because the high dimensionality makes the convergence of the full likelihood function difficult.
[31] For robustness check, we re-estimate the model with the colonial tie dummy variable excluded. The results are barely affected. See the next subsection for detail.

technical measures do serve as quality signals to which consumers respond. This finding contradicts the claim that pure protectionist motives drive these measures. The trade cost effect of OECD technical measures turns out negative and statistically significant, indicating that technical measures adversely affect OECD exporters via increasing variable costs of exports. To gauge the net effect of technical measures, we test the hypothesis that sum of the demand-enhancing effect and the trade-cost effect is zero. The associated F-statistic fails to reject the hypothesis, which implies that the volumes of trade between OECD countries are not severely affected by technical measures because the two effects almost cancel out. Other trade cost terms have the expected signs and magnitudes as typically found in a gravity equation analysis. Specifically, tariffs, other NTBs, and geographic distance are found to impede trade; countries with a common border or a historical colonial tie tend to trade more.

The selection equation is shown in the last column of table 1, technical measures as quality signals increase the propensity of OECD consumers to purchase agricultural products from other OECD countries, as evidenced by a positive and statistically significant demand-enhancing effect. The trade cost effect, on the other hand, decreases exporter's propensity to export, suggesting that the technical measures significantly add to the fixed costs of export.

Table 1. Model results for intra-OECD agricultural trade, 2004

Variable	Trade Equation	Selection Equation	Variable	Trade Equation	Selection Equation
Quality $\theta\beta$	0.140*** (0.036)	0.123*** (0.010)	Colony θb_c	0.040 (0.051)	0.073** (0.024)
Trade Cost $-\theta\gamma$	-0.166*** (0.044)	-0.099*** (0.013)	Language θb_l	N.A.	0.150*** (0.020)
Tariff $-\theta$	-0.988*** (0.086)	-0.363*** (0.026)	Protectionist NTBs θb_p	-0.205*** (0.053)	0.034* (0.019)

Table 1. (continued)

Variable	Trade Equation	Selection Equation	Variable	Trade Equation	Selection Equation
Distance $-\theta b_d$	-1.288*** (0.033)	-0.604*** (0.009)	Protectionist EU NTBs θb_{p_EU} [a]	-0.077 (0.127)	0.040 (0.037)
Border θb_b	0.911*** (0.043)	0.460*** (0.022)	Inverse Mills Ratio[b]	0.726*** (0.075)	

Note: a. The protectionist NTBs adopted by the EU can have different trade effects than those imposed by other OECD countries because intra-EU trade is not subject to EU's NTBs. To capture this potential difference, we allow the response to EU's NTBs to be different. b. The Inverse Mills Ratio is the additional regressor in the trade equation that corrects for the sample selection bias. The significance of the Inverse Mills Ratio confirms the suitability of the Heckman sample selection model. Standard errors are in parenthesis. *, **, and *** denote significance level at 0.1, 0.05, and 0.01 respectively.

The above finding has important implications for small exporters, or firms that are just productive enough to overcome the fixed cost of trade (Melitz, 2003; Chaney, 2008). The proliferation of technical measures places another hurdle for small firms to jump, which could drive them out of foreign markets although results show that higher willingness to pay is generated by the technical measures.

In terms of other trade determinants, tariffs and distance are shown to hinder trade; a common border, a colonial tie in history, or a common language fosters trade new partnership. The protectionist NTBs are shown to be positively correlated with trade propensity, which is unexpected given the presumption of real trade impediment.[32] The significance of the Inverse Mills Ratio confirms the importance of accounting for the selection process and the propensity to open new trade.

To shed more light on the trade effects of technical measures, we compute the extensive margins to trade, the intensive margins to trade, and the overall marginal effects (see Appendix for the derivation). The extensive margin to trade refers to the changes in the

[32] However, the overall marginal effect of protectionist NTBs, with both the extensive margin and the intensive margin taken into account, can be shown to impede trade.

propensity to trade as its determinants change. In the Heckman sample selection model, the extensive margin corresponds to the marginal effect in the selection equation (13b). The intensive margin to trade, on the other hand, describes how trade volumes between existing trading partners respond to changes in underlying determinants. The intensive margin of a trade determinant corresponds to its direct effect, captured by its coefficient in outcome equation (13a), as well as its indirect effect through the sample correction term. The overall marginal effects can then be calculated as the sums of these two margins.

Table 2. Marginal effects of technical measures on intra-OECD agricultural trade

	Intensive margin	**Extensive margin**
Demand-enhancing effect	0.140***	0.142***
	(0.036)	(0.012)
Trade-cost effect	-0.166***	-0.113***
	(0.044)	(0.015)
P value of χ^2-stat for H_0: zero net effect	0.303	0.001

Note: Standard errors are in parenthesis. *, **, and *** denote significance level at 0.1, 0.05, and 0.01.

Table 2 summarizes the extensive and intensive margins of technical measures on intra-OECD agricultural trade in 2004. As shown in the first row in table 2, technical measures appear to serve as quality signals and enhance OECD consumer's quantity demanded as well as the propensity to import from other OECD countries. The second row in table 2 suggests that technical regulations increase both the variable cost and the fixed cost faced by OECD exporters. Noticeably, the magnitude of the extensive margin is comparable to that of the intensive margin, for either effect. To gauge the net effect on both margins, we consider a simple case in which the importing country imposes a new technical measure while the exporting country doesn't. The net effect of this new regulation can be computed as the sum of the demand-enhancing effect and the trade-cost effect. As shown in the third row in table 2, the net effect is positive but not statistically significant on the intensive margin, which suggests that the bilateral trade volume would be barely affected by the new regulation although both supply and demand shift and welfare will be affected. However, the net effect is negative and statistically significant on the extensive margin, which indicates that the new measure is likely to create new trade partnership among OECD members. In other words, the technical measures enhance consumers' demand for imports more than they handicap exporters' supply of exports. These results substantially refine the previous findings of Disdier, Fontagné, and Mimouni (2008) who found that SPS/TBT measures on agricultural commodities imposed by OECD countries had decreased exports from non-OECD countries but slightly promoted intra-OECD trade (although not statistically significant).

Next, we turn to regressions for specific sectors at HS-2 level. A glance at the frequency index of technical measures suggests that the following twelve agricultural sectors are regulated in OECD countries: dairy products (HS-04); live trees, cut flowers (HS-06); edible fruits, nuts (HS-08), coffee, tea, spices (HS-09); cereals (HS-10); milling products (HS-11); meat, fish preparations (HS-16); cereal preparations (HS-19); vegetable preparations (HS-20); edible preparations (HS-21); and beverages, spirits (HS-22). We fit the Heckman sample selection model with each subsample and report in table 3 the simple counts of different demand-enhancing effects and the trade-cost effects. The results on the demand-enhancing effects suggest that the role of technical measures as quality signals increases the chance of intra-OECD trade in eight out of the twelve intensively regulated sectors. Moreover, the volume of trade in three sectors would increase as result of the quality improvement if firms were not affected by the regulations. On the other hand, the estimates of the trade-cost effects indicate that technical measures significantly add to the variable costs of trade in three sectors, and the fixed costs of trade in three sectors. We find positive trade-cost effects on the extensive margin for two sectors, which was surprising. One possible explanation is that the country-specific notifications of technical measures do not capture certain harmonization or mutually recognition of standards, which presumably reduces compliance cost considerably.

Table 3. Summary of sectoral analysis of the effects of technical measures on intra-OECD agricultural trade, 2004

	Intensive margin	**Extensive margin**
Demand-enhancing effect	Positive & stat. significant: 3 Null: 9 Negative & stat. significant: 0	Positive & stat. significant: 8 Null: 4 Negative & stat. significant: 0
Trade-cost effect	Positive & stat. significant: 0 Null: 9 Negative & stat. significant: 3	Positive & stat. significant: 2 Null: 7 Negative & stat. significant: 3

Note: Positive & stat. significant refers to positive and statistically significant at 10% level or lower; Negative & stat. significant refers to negative and statistically significant at 10% level or lower; Null refers to statistically insignificant at 10% level.

Now we focus on two particular sectors, dairy products (HS-04) and cereal preparations (HS-19), in which both consumers and producers in OECD are found to be sensitive to technical measures. SPS/TBT issues in dairy products involve the use of Bst, a genetically engineered growth hormone that increases milk production, a dispute over mandatory pasteurization of cheese, and labeling of yogurts among others (Bureau and Doussin 1999). The technical regulations toward cereal preparations evolve around the Maximum Residue Limits (MRLs) on mycotoxin residues that result from poor farm practice in high temperature and high humidity environments. In 2002, EU harmonized their MRLs on mycotoxins in several sectors, including cereal and vegetable preparations. Compared to the international standards (Codex Alimentarius), EU's harmonized regulation is more stringent in terms of both allowable level and sampling methods, which triggered concerns about the potential trade loss borne by exporters (Otsuki, Wilson, and Sewadeh 2001b). The econometric results for the two sectors are reported in table 4 and the implied marginal effects of regressors in table 5.

Table 4. Model results for intra-OECD trade in dairy products and cereal preparations

Dairy products	Trade Equation	Selection Equation	**Cereal preparation**	Trade Equation	Selection Equation
Quality $\theta\beta$	0.763*** (0.185)	0.144*** (0.049)	Quality $\theta\beta$	0.973*** (0.180)	1.003*** (0.050)
Trade Cost $-\theta\gamma$	-0.848*** (0.216)	-0.205*** (0.057)	Trade Cost $-\theta\gamma$	-0.748*** (0.217)	-0.447*** (0.076)
Tariff $-\theta$	-0.480* (0.264)	-0.221*** (0.076)	Tariff $-\theta$	-0.861 (0.930)	-0.598 (0.372)
Distance $-\theta b_d$	-1.150*** (0.177)	-0.641*** (0.042)	Distance $-\theta b_d$	-1.477*** (0.153)	-0.642*** (0.066)
Border θb_b	1.300*** (0.197)	0.407*** (0.106)	Border θb_b	0.959*** (0.238)	0.166 (0.171)
Colony θb_c	-0.109 (0.254)	0.050 (0.110)	Colony θb_c	-0.073 (0.269)	0.326* (0.190)
Language θb_l	N.A.	0.258*** (0.096)	Language θb_l	N.A.	0.359** (0.145)
Protectionist NTBs θb_p	0.270 (0.501)	-0.073 (0.078)	Protectionist NTBs θb_p	0.014 (0.755)	-0.509* (0.296)
Inverse Mills Ratio	0.718 (0.390)		Inverse Mills Ratio	0.212 (0.359)	

Note: Inverse Mills Ratio is defined as in table 1. Standard errors are in parenthesis. *, **, and *** denote significance level at 0.1, 0.05, and 0.01 respectively.

Table 5. Marginal effects on intra-OECD trade in dairy products and cereal preparations

Dairy products	**Intensive Margin**	**Extensive Margin**	**Cereal preparation**	**Intensive Margin**	**Extensive Margin**
Demand-enhancing Effect	0.763*** (0.185)	0.163*** (0.057)	**Demand-enhancing Effect**	0.973*** (0.180)	0.779*** (0.046)
Trade-cost Effect	-0.848*** (0.216)	-0.232*** (0.065)	**Trade-cost Effect**	-0.748*** (0.217)	-0.347*** (0.061)
H_0: zero net effect			H_0: zero net effect		
P value of χ^2-stat	0.417	0.025	P value of χ^2-stat	0.260	0.000

Note: Delta-method standard errors are in parenthesis. *, **, and *** are as defined in previous tables.

We first discuss the results for dairy products. As shown in table 4, both the demand-enhancing effect and the trade-cost effect bear the expected signs and turn out statistically significant. In terms of the magnitude, table 5 suggests that the technical measures on dairy products depress the supply of exports more than they enhance consumer's demand via information discloser and quality improvement. In fact, if an OECD importer adopts a new regulation while the trading partner doesn't, the new measure would reduce the likelihood of trade between the two countries, as the net effect on the extensive margin is negative and statistically significant. The above results suggest that although OECD consumers in general place a premium on the dairy products of higher quality, but the compliance costs borne by producers prevent them from adopting new technologies and capturing some of these markets.

Regarding cereal preparations, table 4 shows that both OECD consumers and producers seem to respond to technical regulations, with the demand-enhancing effect dominating the trade-cost effect in magnitude. Table 5 further confirms that agents on both sides of the market are affected by the technical measures, and that a new regulation is likely to increase the chance of intra-OECD trade in cereal preparations. The trade-promoting attribute of technical regulations in cereal products reflect several facts. OECD consumers are visibly concerned about mycotoxin contamination in food stuff and they are willing to pay a sizable premium for high-quality cereal products. For OECD exporters who are able to conform to these costly regulations, trade expands. Not captured here but documented elsewhere is the fact that non-OECD exporters have difficulty meeting these standards (Disdier, Fontagné, and Mimouni, 2008; Otsuki, Wilson, and Sewadeh, 2001b) inducing some changes in sourcing these products from new OECD suppliers meeting the stricter standards.

The estimates of other trade determinants, in both sectors, are in line with a typical gravity equation analysis. Tariffs are found to be trade-impeding; the farther apart two countries are, the less the bilateral trade there is; a shared border and a common language between trading partners facilitate trade; NTBs other than technical regulations do not significantly affect the intra-OECD trade in dairy products and cereal preparations.

Robustness and Specification Checks

In this subsection, we conduct several robustness checks for our empirical application. One concern about the Heckman sample selection model is that it requires a variable in the selection equation to be excluded from the outcome equation. To see to the influence of the choice of excluded variable on results, we re-estimate the models when the colonial tie dummy variable in excluded. The associated results are almost identical to those reported in table 2 through 5.[33]

Another criticism toward the use of the Heckman sample selection model is that the estimates can be biased if trade flow exhibits heteroskedasticity. One remedy to the problem is to use the PPML approach proposed by Silva and Tenreyro (2006), in which the gravity equation is estimated in its multiplicative form instead of the logarithmically linear form and robust standard errors are used to accommodate heteroskedasticity. However, as Pham and Marin (2008) show, the PPML approach ignores the limited dependency of the trade flow and fails to explain the absence of trade. A variant to the PPML approach is the Zero-Inflated Poisson Pseudo Maximum Likelihood (ZIPPML) estimator which improves upon the

[33] The econometric results are available from authors upon request.

standard PPML approach by accounting for the excessive zeros (Burger, van Oort, and Linders, 2009). One disadvantage with the ZIPPML approach is that the estimates vary as to the unit of the dependent variable varies.[34] Nevertheless, we conduct the ZIPPML regressions and compare the results to those delivered by the Heckman models. In the augmented regressions, the demand-enhancing effects and the trade-cost effects found are qualitatively similar except that the trade-cost effect becomes positive in the pooled regression.[35] The technical measures are shown to promote intra-OECD agricultural trade overall.

Conclusions

In this article, we propose a generalized gravity equation model in which the demand-enhancing effect and the trade cost effect of technical measures can be disentangled. The approach allows examining whether technical measures affects international trade, if any, through shifting consumers' demand curve via quality information disclosure, or shifting exporters' supply curve via imposing compliance costs, or both. An application of the approach to the intra-OECD agricultural trade in 2004 suggests that technical measures foster trade within OECD because these measures enhance consumers' demand for imports more than they hamper exporters' supply of exports. Although we do not investigate North-South trade, our findings are relevant to the debate on "standards as barrier to or catalyst for trade." We find that the willingness to pay of consumers in OECD countries increases with stricter regulation affecting quality of food. Hence, these standards do create new market

[34] Both the selection and the outcome processes can generate zeros in the ZIPPML model. Hence, more zeros are attributed to the selection process when trade data are recoded say in dollars as opposed to in millions of dollars.
[35] The econometric results are available from authors upon request.

opportunities for exporters. We do not say anything on how exporters in the South succeed or fail to capture these markets. Nevertheless, the allegation that these technical measures are mostly driven by protectionism is invalid.

More disaggregated analysis reveals that technical regulations on dairy products affect both consumers and producers in OECD, with trade-cost effect slightly dominating the demand-enhancing effect. On the other hand, technical measures on cereal preparations are shown to promote intra-OECD trade in the net because the enhancement of demand for high-quality cereal products outweighs the decrease of supply due to the associated compliance costs.

A promising extension would be to compile a panel data set and investigate the welfare effects of changes in technical measures. The time variation would allow the identification of all structural parameters in the proposed model and facilitate the computation of domestic and international welfares. Furthermore, one could also explicitly consider additive external effects on human/animal health and the environment based on currently available scientific evidence, which allows predicting the welfare implications of technical measures in the long-run.

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Appendix

Derivation of intensive margins, extensive margins, and unconditional marginal effects in the Heckman sample selection model

In general, the selection equation determining firms' self-selection to export is specified as

(A1) $\Pr(Y > 0) = \Phi(X\gamma).$

The outcome equation generating the trade flows conditional on trade taking place is specified as

(A2) $E(\ln Y \mid Y > 0) = \sum_k x_k \beta_k + \eta IMR,$

Let $z = x' \cdot \hat{\gamma}$ be the linear prediction from the selection equation; $IMR = \phi(\hat{z})/\Phi(\hat{z})$ is the Inverse Mill's Ratio as in Heckman (1979), which corrects for the sample selection bias. Applying the rules of conditional expectations, we have

$$E(Y) = E(Y \mid Y > 0) \cdot \Pr(Y > 0) + E(Y \mid Y = 0) \cdot \Pr(Y = 0) = E(Y \mid Y > 0) \cdot \Pr(Y > 0).$$

Taking the logarithm of the above equation, and then taking the derivative with respect to an exogenous variable, x_k for instance, we have

$$\text{(A3)} \qquad \frac{\partial \ln E(Y)}{\partial x_k} = \frac{\partial \ln E(Y \mid Y > 0)}{\partial x_k} + \frac{\partial \ln \Pr(Y > 0)}{\partial x_k}.$$

The above equation states that the overall marginal effect can be decomposed into an *intensive margin* $\frac{\partial \ln E(Y \mid Y > 0)}{\partial x_k}$, that is, the intensification of existing trade flows, and an *extensive margin* $\frac{\partial \ln \Pr(Y > 0)}{\partial x_k}$, that is, the creation of new trade. Note that the extensive margin can be readily computed from the estimates in the selection equations.

As Hoffman and Kassouf (2005) shows, $\frac{\partial \ln E(Y \mid Y > 0)}{\partial x_k} = \frac{\partial E(\ln Y \mid Y > 0)}{\partial x_k}$ holds under some regular conditions.[1] Therefore, the intensive margin can be computed as

$$\text{(A4)} \qquad \frac{\partial \ln E(Y \mid Y > 0)}{\partial x_k} = \frac{\partial E(\ln Y \mid Y > 0)}{\partial x_k} = \hat{\beta}_k + \left(\frac{\phi'(z)}{\Phi(z)} - IMR^2\right)\eta \hat{\gamma}_k,$$

where $\phi'(z) = -\frac{z}{\sqrt{2\pi}} \exp(-0.5 z^2)$ is the derivative of the standard normal density function. The above equation states that a trade determinant affects the trade level both directly and indirectly.

CHPATER 4. ESTIMATING GRAVITY EQUATION MODELS IN THE PRESENCE OF HETEROSKEDASTICITY AND FREQUENT

Abstract

Gravity equation models are widely used in international trade to assess the impact of various policies on the patterns of trade. Although recent literature provides solid micro-foundations for the gravity equation model, there is no consensus on how to estimate a gravity equation model in the presence of the two stylized features of trade data: frequent zeros and heteroskedasticity. We propose a Two-Step Nonlinear Least Square estimator that satisfactorily deals with both problems. Monte-Carlo experiments show that the proposed estimator strictly outperforms the Poisson Pseudo Maximum Likelihood (PPML), the Heckman sample selection model, and the E.T.-Tobit estimators, and that it weakly dominates the Truncated PPML model in the estimation of the intensive margin of trade. An empirical study of world trade in 1986 suggests that currency union and regional trade agreements facilitate trade primarily through improving market access, as opposed to intensifying pre-existing trade.

Introduction

The gravity equation model has been a long-time workhorse in international trade since Tinbergen (1962). It posits that the bilateral trade flow between any two countries can be explained by the two countries' income levels, geographic distance, and various other factors that affect trade cost (such as import tariffs, non-tariff regulations, contiguity condition, historical colonial relationship, and religion similarity). In the past decade, the gravity equation model has received even more recognition because of the development of its microeconomic foundations.[36] Following Anderson (1979), Anderson and van Wincoop (2003) derives a full specification of the gravity equation model with trade costs based on the utility maximization behavior of a representative consumer with Constant Elasticity of Substitution (CES) preferences. Most importantly, they emphasize the importance of controlling for countries' multi-lateral trade resistance terms in a cross-sectional gravity equation analysis. Novy (2010) innovates a gravity equation in a general equilibrium setting with a translog demand system. Markusen (1986) and Bergstrand (1985, 1989) introduce non-homothetic preferences in gravity equation models and explain the role of per-capital income in shaping trade patterns. Deardorff (1998) shows that a gravity equation can emerge from a Heckscher-Ohlin framework as well. Evenett and Keller (2002) report that both the Heckscher-Ohlin theory and the monopolistic-competition trade theory can guide the gravity equation and that they provide insights to different components of the international variation of production and trade patterns. In a comprehensive review, Feenstra, Markusen, and Rose (2001) examine how various trade theories are linked to the gravity equation approach and provide evidence in favor of the monopolistic-competition theory and the reciprocal-dumping theory. More recently, Helpman, Melitz, and Rubinstein (2008) build up a generalized gravity equation from the behavior of firms that are heterogeneous in productivity and faced with fixed costs of exporting. Their model predicts that only the most productive firms are able to overcome the fixed cost of trade and penetrate foreign markets, and that trade liberalization induces more firms to participate in the world market.

[36] Interested readers are referred to Anderson (2011) for a thorough review on the theoretical and empirical developments of the gravity equation approach to trade.

Although the microeconomic foundations of the gravity equation approach are well established, there is no consensus in the literature on how to statistically estimate a gravity equation in the presence of the two stylized features of trade data: frequent zeros and heteroskedasticity.[37] On the one hand, the presence of zeros is quite common in trade data. In a cross-sectional analysis at the national level, e.g. Silva and Tenreyro (2006) and Helpman, Melitz, and Rubinstein (2008), nearly 50% of the trade records are zeros. Even with panel data sets covering more recent years in agricultural trade, e.g., Sun and Reed (2010) and Grant and Boys (2012), the percentage of zeros is above 30%. The proper treatment of those zero trade flows is warranted from both the statistical and the economic viewpoints. Statistically, since zeros generally reflect countries' inability to overcome the fixed cost of creating a trade partnership, the omission of such non-random zeros results in sample selection bias (Heckman, 1979). From an economic perspective, any mistreatment of zeros limits the model's insights into how trade polices improve or hinder market access for small or sporadic traders, or the extensive margins to trade.[38] The latter is of particular importance when the policies of interest play a major role in determining the cost of entering or surviving in world market. Shepherd (2010) shows the reduction in export costs, tariffs, and transport costs encourages developing countries to export to more destinations. Besedes and Prusa (2011) argue that developing countries are more likely to experience long-run export growth

[37] Other empirical issues in the gravity equation model include how to control for the multi-lateral trade resistance terms, e.g., Baldwin and Taglioni (2006) and Baier and Bergstrand (2009), how to deal with endogeneity, e.g., Egger (2004) and Baier and Bergstrand (2007), etc. These topics are beyond the scope of the current study.

[38] Throughout the paper, we refer to the extensive margin to trade as the newly created trade partnership between countries. We do not deal with the newly entered firms (Helpman, Melitz, and Rubinstein, 2008), or the newly traded varieties (Hummels and Klenow, 2005) or the newly reached consumers (Akolakis, 2011) because we focus on aggregate trade flows.

if new entrants to world market have a better chance to survive beyond the first year.[39] Bergin and Lin (2009) demonstrate that currency unions facilitate international trade predominantly through increasing the number of exporting firms and the number of traded products.

On the other hand, trade data often exhibit heteroskedasticity. The data sample of a gravity equation analysis usually consists of bilateral trade flows among countries that are different in so many characteristics that heteroskedasticity is likely to prevail. The direct implication of possible heteroskedasticity is that the gravity equation model should be estimated in its original multiplicative form, as opposed to its linear form after the logarithmic transformation. In fact, as Silva and Tenreyro (2006) show, estimates from log-linearized gravity equation models are generally biased because the logarithmic transformation makes the error terms correlated with the explanatory variables. Needless to say, the presence of pervasive zeros and heteroskedasticity disqualifies the conventional Ordinary Least Square estimator that had been used for decades. As more advanced estimators for the gravity equation model are being suggested, two camps emerge in the literature.

One camp in the debate focuses on the economics of zero trade flows. The new trade theory, e.g., Melitz (2003), Chaney (2008), and Helpman, Melitz, and Rubinstein (2008), posits that the absence of trade results from firms' self-selection behavior: zero trade flow is observed when none of the firms in the potential exporting country is productive enough to overcome the fixed costs. Therefore, zeros can be seen as generated from a selection process,

[39] By using transactions data from several developing countries, Rauch (2011) points out that firms more diversified in terms of products and destinations are more likely to survive in the world market.

which naturally calls for the Heckman sample selection model (Heckman, 1979), or, to a less degree, the E.T.-Tobit (Eaton and Tamura, 1994) model. In a Heckman sample selection model, the zeros are attributed to a selection process that characterizes the agents' self-selection behavior. Conditioning on agents' self-selection to trade, the volume of trade, in its log-scale, is then explained by various trade determinants and one additional term correcting for the potential sample selection bias. In a similar spirit, the E.T.-Tobit model considers zeros as censored outcomes and assumes that there is minimal threshold to jump if trade flows are to be observed. The main advantage of the Heckman sample selection model or the E.T.-Tobit model is that both connect well with trade theories and deliver rich comparative statics. In particular, with the Heckman sample selection model or the E.T.-Tobit model, one can decompose the effect of trade liberalization into the intensive margin, or the intensification of existing trade, and the extensive margin, or the creation of new trade partnership. From an international development viewpoint, the identification of the extensive margin is relevant if the question of interest is how small exporters' access to foreign markets is affected. Nevertheless, built upon the log-linearized version of the gravity equation, the Heckman sample selection model or the E.T.-Tobit model may deliver inconsistent estimates when trade data exhibits heteroskedasticity, because the error terms often evolves with explanatory variables after the logarithmic transformation.

The other camp in the debate advocates estimating the gravity equation in its multiplicative form and resorting to a variant of the count data models. Silva and Tenreyro (2006) propose the Poisson Pseudo Maximum Likelihood (PPML) estimator for the gravity equation model. By estimating the gravity equation in its multiplicative form, the PPML estimator avoids the logarithmic transformation and can be shown to be robust to a wide range of heteroskedastic patterns. However, Martin and Pham (2008) note that the PPML estimates are severely biased when zero records are frequent and the trade data is limitedly dependent in nature. Although Silva and Tenreyro (2011) reply that the PPML estimator is adaptive to prevalent zeros, it fails to separate the extensive margins from the intensive margins. Burger, Linders, and Oort (2009) consider several extensions of the PPML estimator, i.e., the Negative Binomial Pseudo Maximum Likelihood estimator (NBPML), the Zero Inflated Poisson Pseudo Maximum Likelihood estimator (ZIPPML), and the Zero Inflated Negative Binomial Pseudo Maximum Likelihood estimator (ZINBPML). In spite that all three variants have their own advantages, such as allowing over-dispersion and excessive zeros, none of them is robust to the re-scaling of the dependant variable (e.g., measuring trade in dollars or in thousands of dollars gives different estimates). Such drawback arguably prevents NBPML, ZIPPML, and ZINBPML from being widely used.

We reconcile the two camps by proposing a Two-Step Nonlinear Least Square (TS-NLS) estimator that proves robust to pervasive zeros and heteroskedasticity. The estimator works as follows. In the first step, all zeros are explained by a selection process in which the country-pair decide to trade or not, and the extensive margins are computed accordingly. In the second step, positive trade flows are characterized by a gravity equation in its multiplicative form, augmented by one extra term correcting for the sample selection bias. A weighted Nonlinear Least Square method, coupled with robust covariance estimates (White, 1980), is used to estimate the augmented gravity equation and derive the intensive margin. The Monte-Carlo experiments suggest that the proposed TS-NLS estimator strictly dominates the Heckman, PPML, and E.T.-Tobit models, and that it weakly outperforms the Truncated PPML model in term of the estimation of the intensive margin. Additionally, the TS-NLS sheds light on the extensive margin of trade to which the Truncated PPML fails to address. An empirical study of world bilateral trade in 1986 shows that currency union and regional trade agreements promote trade primarily through improving market access (or the extensive margin), rather than via intensifying pre-existing trade (or the intensive margin).

The rest of the chapter is organized as follows. Section 2 describes the gravity equation model setup and proposes the Two-Step Nonlinear Least Square estimator. Section 3 uses a set of Monte-Carlo experiments to evaluate the performance of the proposed estimator relative to its competitors. Section 4 applies the TS-NLS estimator to the dataset in Helpman, Melitz, and Rubinstein (2008) and discusses the trade effects of currency unions and regional trade agreements. Section 5 concludes the presentation and suggests directions for future research.

The Gravity Equation and the Two-Step Nonlinear Least Square Estimator

International trade theory underlying the gravity equation approach posits that Country j's import from Country i can be characterized by the following equation:

(1) $$T_{ij} = X_i^{\alpha} X_j^{\beta} \big/ D_{ij}^{\gamma},$$

where X_i and X_j are Country i and j's characteristics respectively. Such characteristics usually include each country's GDP, total population, per-capita income, remoteness to the rest of the world, etc. D_{ij} contains any trade cost terms that are specific to the particular country-pair, e.g., applied tariff rates, geographic distance, contiguity condition, historical colonial relationship, religion similarity, and the existence of preferential trade agreements.[40]

[40] Interested readers are referred to Anderson and van Wincoop (2004) for a detailed discussion of the modeling of trade costs.

α, β, and γ are parameters to be estimated. Noticeably, the bilateral trade flow, T_{ij}, is always positive according to (1). However, in practice, we frequently observe some countries not trading with each other, or not trading certain commodities in certain years. Therefore, (1) by itself does not constitute a complete specification when it comes to statistical estimation.

To explicitly account for the absence of trade , we introduce a selection process to capture countries' self-selection to trade/not trade. Specifically, we set up the empirical gravity equation model as follows:

(2a) $T_{ij}^{*} = X_i^{\alpha} X_j^{\beta} \big/ D_{ij}^{\gamma} + \mu_{ij}$,

(2b) $d_{ij}^{*} = \tilde{\alpha}\tilde{X}_i + \tilde{\beta}\tilde{X}_j + \tilde{\gamma}\tilde{D}_{ij} + \upsilon_{ij}$,

(2c) $d_{ij} = I(d_{ij}^{*} > 0)$,

(2d) $T_{ij} = d_{ij} T_{ij}^{*}$,

where T_{ij}^{*} is the *notional* trade flow from country i to country j when the two countries decide to trade.[41] d_{ij}^{*} is the latent variable for the binary outcome d_{ij} which equals one if the two countries trade, and 0 otherwise; T_{ij} is the *observed* trade flow. As in Heckman (1979), we assume μ_{ij} and υ_{ij} are two idiosyncratic terms following a bivariate normal distribution.[42] Specifically, $\begin{pmatrix} u_{ij} \\ \upsilon_{ij} \end{pmatrix} \to N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_{11ij} & \sigma_{12ij} \\ \sigma_{21ij} & \sigma_{22ij} \end{pmatrix}\right]$, where $\sigma_{12ij} = \sigma_{21ij} \equiv \sigma_{ij}$. The correlation between the two idiosyncratic terms can be caused by some omitted variables that

[41] The concept of the notional trade is similar to the desired amount of trade as defined by Ranjan and Tobias (2007).
[42] Without any distributional assumption, it is difficult to deal with the issue of sample selection, unless an informative instrumental variable is available. See Wang, Shao, and Kim (2011) for a case study of the instrumental variable approach.

both affect the fixed costs and the variable costs of bilateral trade. Noticeably, the variance of u_{ij}, σ_{11ij}, varies across observations, allowing possible heteroskedasticity. The model setup, (2a)-(2d), is appealing in several aspects. First of all, the gravity equation, (2a), is expressed in its multiplicative form, thus is free from the bias due to logarithmic transformation. Furthermore, as elaborated below, when the conditional (on trade taking place) expectation of (2d) is correctly derived, a nonlinear least square procedure can be used to yield consistent estimates even if heteroskedasticity prevails. Secondly, (2b)-(2c) fully attributes zero trade flows to countries' self-selection not to trade. Moreover, any factor potentially affecting the fixed costs of creating trade partnership can be included in (2b). Thirdly, the characterization of observed trade flows in (2d) facilities the decomposition of the extensive and intensive margins to trade: a potential trade determinant can affect the bilateral trade, T_{ij}, either by varying the market accessibility, d_{ij}, or by altering the volume of trade, T_{ij}^*, or both.

The system (2a)-(2d) is estimated via a two-step procedure. In the first step, we estimate (2b)-(2c) via a standard Probit model.[43] Mathematically, the probability of observing a positive trade from Country i to Country j is represented as:

(3a) $$\Pr(d_{ij}=1)=\Phi((\tilde{\alpha}\tilde{X}_i+\tilde{\beta}\tilde{X}_j+\tilde{\gamma}\tilde{D}_{ij})/\sqrt{\sigma_{22ij}})\equiv\Phi(W_{ij}\cdot\theta).$$

Defining the extensive margin to trade as the marginal effect on the log-scaled probability of trade, we compute the extensive margin with respect to a change in x_{ij} as

(3b) $$\partial\ln(\Pr(d_{ij}=1))\big/\partial x_{ij}=\tilde{\gamma}_{x_{ij}}/\sqrt{\sigma_{22ij}}\,\varphi(W_{ij}\cdot\theta)\big/\Phi(W_{ij}\cdot\theta).$$

[43] To allow heteroskedasticity in the Probit model, we use the robust variance-covariance estimates (White, 1980) for the purpose of inference.

In the second step, we characterize the volume of trade conditioning on trade taking place. Since μ_{ij} and υ_{ij} follow a bivariate normal distribution with covariance σ_{ij}, one can derive the conditional mean of the observed trade flow as:

(4a) $$E(T_{ij} \mid d_{ij} = 1) = X_i^{\alpha} X_j^{\beta} \big/ D_{ij}^{\gamma} + \sigma_{ij} / \sqrt{\sigma_{22ij}} \lambda_{ij} .$$

where $\lambda_{ij} = \varphi(W_{ij}\hat{\theta}) \big/ \Phi(W_{ij}\hat{\theta})$ is the Inverse Mill's Ratio (Heckman, 1979) calculated from the first-step estimation. Intuitively, (4a) states that the observed trade flow can be explained by a gravity equation augmented by an additional term that corrects for the potential sample selection bias. In the extreme case where the error terms in the outcome process (2a) and the selection process (2b) are uncorrelated, or $\sigma_{ij} = 0$, (4a) reduces to a conventional gravity equation in its multiplicative form. Furthermore, one may speculate that size of trade amplifies sample selection bias: if the size of trade is large, the actively exporting countries are presumably much more productive than non-exporting countries, which means that investigating actively trading countries only leads to a more selected sample. Therefore, we posit that $\sigma_{ij} / \sqrt{\sigma_{22ij}}$ is proportional to the size of trade. Specifically,

(4b) $$\sigma_{ij} / \sqrt{\sigma_{22ij}} = \omega X_i^{\alpha} X_j^{\beta} \big/ D_{ij}^{\gamma} ,$$

where ω is a parameter to be estimated.[44] Substituting (4b) into (4a), we have

(4c) $$E(T_{ij} \mid d_{ij} = 1) = X_i^{\alpha} X_j^{\beta} \big/ D_{ij}^{\gamma} \cdot (1 + \omega \lambda_{ij}) .$$

We can estimate (4c) via the weighted nonlinear least square method as in Silva and Tenreyro (2006). The resulting estimates are consistent as long as (4c) is correctly specified. Moreover, we use the heteroskedasticity-consistent covariance matrix estimator (White,

[44] As a sensitivity analysis in Section 3 shows, TS-NLS estimates are biased when the assumption does not hold. However, estimates delivered by alternative models are even more biased.

1980) to construct standard errors, so that the statistical inference is resistant to heteroskedasticity in the gravity equation. The intensive margin to trade, defined as the marginal effect on the percentage change in the volume of trade is computed as:

$$\text{(4d)} \quad \partial \ln(E(T_{ij} \mid d_{ij}=1)) / \partial x_{ik} = \beta_k + \theta_k [\frac{\omega}{1+\omega\lambda_{ij}} (\frac{\phi'(W_{ij}\theta)}{\Phi(W_{ij}\theta)} - \lambda_{ij}^2)],$$

where $\varphi'(\cdot)$ is derivative of the normal density function. Intuitively, (4d) shows that the intensive margin consists of two parts, with the direct impact given by β_k and the indirect impact, through affecting the self-selection behavior, represented by the second term on the right hand side. The overall marginal effect, if the variable of interest is deemed to affect both the fixed and variable costs of trade, is simply the sum of the extensive margin (3b) and the intensive margin (4d):

$$\text{(5a)} \quad \partial \ln E(T_{ij}) / \partial x_{ij} = \partial \ln(\Pr(d_{ij}=1)) / \partial x_{ij} + \partial \ln(E(T_{ij} \mid d_{ij}=1)) / \partial x_{ij},$$

or,

$$\text{(5b)} \quad \partial \ln E(T_{ij}) / \partial x_{ij} = \beta_k + \theta_k [\frac{\omega}{1+\omega\lambda_{ij}} (\frac{\varphi'(W_{ij}\theta)}{\Phi(W_{ij}\theta)} - \lambda_{ij}^2) + \lambda_{ij}].$$

We now compare the proposed TS-NLS estimator with the alternative estimators in the literature, i.e., the Heckman model, the E.T.-Tobit model, and the PPML estimator.[45] The treatment of zeros in the TS-NLS estimator is similar to that in the Heckman sample selection model or the E.T.-Tobit model: all three models attribute zeros to countries' self-selection to no trade. However, only the TS-NLS model is free from the logarithmic transformation bias. Another advantage of the proposed TS-NLS estimator over the Heckman

[45] We do not consider the variants of PPML, namely, NBPML, ZIPPML, and ZINBPML, because of their vulnerability to re-scaling of the dependent variable, as mentioned above.

procedure is that the identification of the TS-NLS model does not require an excluded variable in practice.[46] Compared to the PPML estimator which uses one single process to explain both positive and zero trade flows, the TS-NLS model accommodates zeros in a way that coherently follows the implications of the new trade theory and allows researchers to disentangle the intensive margins to trade and the extensive margins to trade. To further identify the sources of bias inherited in the PPML estimator, we derive the unconditional expectation from (4c) and get

(6) $$E(T_{ij}) = X_i^{\alpha} X_j^{\beta} \big/ D_{ij}^{\gamma} \cdot (1+\omega\lambda_{ij}) \cdot \Phi(W_{ij} \cdot \theta) .$$

Hence, the PPML estimates are generally biased due to its ignorance of both the sample selection issue and the impact from the extensive margin. A glance at (4c) also suggests that the TS-NLS model nests the truncated PPML model, i.e., a PPML model applied to the subsample containing positive trade flows only, as a special case when idiosyncratic terms in the selection process and the outcome process are uncorrelated ($\omega = 0$). Admittedly, the consistency of the proposed TS-NLS estimates relies on the joint normality assumption. In particular, the conditional mean of (4c) could be mis-specified if the normality assumption was violated. A specification test can be used to justify the normality assumption. As we show in Section 4, the specification in (4c) easily survives the Reset specification test (Ramsey, 1969).

The Monte-Carlo Experiments

In this section, we conduct a set of Monte-Carlo experiments to assess the performance of the proposed TS-NLS estimator and the alternative estimators: the PPML model, the Heckman

[46] The near linearity of the Inverse Mills' Ratio often makes the second stage of the Heckman procedure unidentifiable. See Puhani (2000) for more detailed discussions.

procedure, and the E.T.-Tobit model. To investigate the finite sample properties of each estimator, we report its bias, variance, and mean square error.[47]

For simplicity, we introduce two explanatory variables x_1 and x_2. Mimicking a continuous trade cost (such as distance), x_1 is a continuous variable drawn from a normal distribution with mean 0 and variance 0.1, i.e., $x_1 \sim N(0, 0.1)$.[48] To proxy a categorical trade cost term (such as colonial relationship), x_2 is constructed as a binary variable that follows a Bernoulli distribution with 0.4 as its probability of success, i.e., $x_2 \sim Bern(0.4)$. The data is generated from the following system.

(6a) $T_i^* = \exp(\beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i}) + \mu_i$,

(6b) $d_i^* = \gamma_0 + \gamma_1 x_{1i} + \gamma_2 x_{2i} + \upsilon_i$,

(6c) $d_i = I(d_i^* > 0)$,

(6d) $T_i = d_i \cdot T_i^*$,

where $\begin{pmatrix} u_i \\ v_i \end{pmatrix} \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_{11i} & \sigma_{12i} \\ \sigma_{21i} & \sigma_{22i} \end{pmatrix}\right]$, and $i = 1, 2, ..N$. We assign the following true values for the parameters in (6a): $\beta_0 = -0.5$, $\beta_1 = \beta_2 = 1$. To allow heteroskedasticity, we consider three functional forms for σ_{11i}: (i) homoskedastic errors, or $\sigma_{11i} = 0.015$; (ii) heteroskedastic errors, i.e., the variance is proportional to the mean, or $\sigma_{11i} = 0.03 m_i$, where $m_i \equiv \exp(\beta_0 + \beta_1 x_{1i} + \beta_1 x_{2i})$; (iii) super-heteroskedastic errors, i.e., the variance is a quadratic functional form of the mean, or $\sigma_{11i} = 0.02 m_i + 0.02 m_i^2$.

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[47] We do not investigate the asymptotic properties because the objective of allowing heteroskedasticity rules out a full likelihood characterization.
[48] We set a relative small variance because the variation gets larger after the exponential transformation.

Now we turn to the parameterization of the selection process (6b)-(6c). We set $\gamma_1 = 1$, so that the factor represented by x_1 positively affects the outcome T through both the selection and outcome processes. We let $\gamma_2 = 0$, so that the variable proxi-ed by x_2 influences the outcome process only. In the context of international trade, we can interpret x_1 as some determinant that potentially affects both the decision to trade and the trade volume, and consider x_2 as a factor merely impacting the trade volume. We consider two true values of γ_0: either $\gamma_0 = 0.85$, in which case zeros account for about 20% of the sample, or $\gamma_0 = 0$, in which case zeros take up 50% of all observations. We refer to the formal case as the "few zeros" scenario and the latter as the "many zeros" scenario. We set $\sigma_{22i} = 1$ (A sensitivity analysis will be conducted later to allow heteroskedasticity in the selection process). Lastly, we assume the covariance between the two idiosyncratic terms is proportional to the mean of the outcome process, i.e., $\sigma_{12i} = 0.04 m_i$ (A sensitivity analysis of this proportionality assumption will be conducted later in the section). Given the true values of σ_{11i} and σ_{22i}, such parameterization of σ_{12i} implies that the average correlation between the selection process and the outcome process, conditioning on all observables, is 0.35 in (i), 0.23 in (ii), and 0.20 in (iii).

To sum up, we have a total of six scenarios: (1) few zeros and homoskedastic errors, (2) few zeros and heteroskedastic error, (3) few zeros and super-heteroskedastic error, (4) many zeros and homoskedastic error, (5) many zeros and heteroskedastic error, and (6) many zeros and super-heteroskedastic error. Under each scenario, we generate a sample of 1000 observations ($N = 1000$) and apply each estimator to the data. We iterate the exercise for 1000 times and report the results in Table 1.

Table 1. Simulation results under six scenarios

estimator	x	Few zeros (20%) Bias $\hat{\beta}-1$	Var. $\mathrm{var}(\hat{\beta})$	Mean Square Error	Many zeros (50%) Bias $\hat{\beta}-1$	Var. $\mathrm{var}(\hat{\beta})$	Mean Square Error
Homoskedasticity: the variance is a constant							
PPML	1	0.334	0.033	0.145	0.770	0.158	0.750
	2	0.002	0.001	0.001	-0.001	0.004	0.004
T-PPML	1	-0.016	0.002	0.002	-0.017	0.010	0.011
	2	0.001	0.000	0.000	0.000	0.000	0.000
Heckman	1	-0.133	2.908	2.926	0.042	14.73	14.74
	2	0.020	0.878	0.878	-0.025	1.241	1.241
Tobit	1	-0.349	1.375	1.497	-0.030	2.716	2.717
	2	-0.694	0.052	0.534	-0.801	0.034	0.676
TS-NLS	1	-0.010	0.002	0.002	-0.023	0.003	0.003
	2	0.001	0.000	0.000	0.000	0.000	0.000
Heteroskedasticity: the variance is linear in the mean							
PPML	1	0.318	0.034	0.136	0.768	0.157	0.747
	2	0.000	0.001	0.001	0.003	0.004	0.004
T-PPML	1	-0.016	0.004	0.004	-0.013	0.015	0.015
	2	0.000	0.000	0.000	0.001	0.000	0.000
Heckman	1	-0.063	3.505	3.509	0.043	18.44	18.44
	2	0.045	2.470	2.472	0.073	7.526	7.531
Tobit	1	-0.285	1.284	1.365	-0.014	2.804	2.804
	2	-0.675	0.054	0.510	-0.800	0.033	0.674
TS-NLS	1	-0.008	0.004	0.004	-0.014	0.006	0.006
	2	0.000	0.000	0.000	0.001	0.000	0.000
Super-Heteroskedasticity: the variance is quadratic in the mean							
PPML	1	0.324	0.045	0.149	0.742	0.169	0.720
	2	0.001	0.001	0.001	-0.003	0.005	0.005
T-PPML	1	-0.012	0.006	0.006	-0.017	0.014	0.014
	2	0.000	0.000	0.000	0.000	0.000	0.000
Heckman	1	0.127	5.001	5.017	0.279	85.21	85.29
	2	0.000	0.317	0.317	-0.056	1.785	1.788
Tobit	1	-0.277	1.552	1.629	-0.046	3.022	3.025
	2	-0.676	0.056	0.513	-0.804	0.036	0.682
TS-NLS	1	-0.002	0.006	0.006	-0.017	0.009	0.009
	2	0.000	0.000	0.000	0.000	0.000	0.000

We discuss the performance of each estimator in turn. As shown in Table 1, the PPML estimates of β_1 are biased upward by more than 30% when zeros are few, and by more than 70% when zeros are many. The reason is that, without differentiating the selection process from the outcome process, the PPML estimates tend to co-find the effects through β_1

and γ_1, as illustrated by (6). Moreover, as the percentage of zeros increases, the impact from the selection process assumes more weight, leading to more biased PPML estimates. On the other hand, the PPML estimates of β_2 are close to the true value, with the bias below 0.2% when zeros are few and below 0.3% when zeros are many, because the variable of interest affects the outcome stage only. Overall, as in Martin and Pham (2008), we find that the PPML estimates can be severely biased when the outcome is limitedly dependent in nature.[49] Nevertheless, the PPML results are quite stable across different heteroskedastic patterns, as claimed in Silva and Tenreyro (2006). Interestingly, the Truncated PPML model performs better than the regular PPML model. Specifically, its estimates of β_1 and β_2 are biased downward by less than 2% and 0.1% respectively. This is because the only source of bias in the Truncated PPML procedure, according to (4c), is the ignorance of non-random sample selection. In terms of the direction of the bias, since the correlation between the two idiosyncratic terms is assumed to be positive and the Inverse Mill's Ratio is a decreasing function, we expect the Truncated PPML model to under-estimate the true effects. In addition, the variances of the Truncated PPML estimates increase rapidly as the proportion of zeros increases, suggesting that the Truncated PPML model suffers from efficiency loss due to its ignorance of zero outcomes.

Now we turn to the Heckman sample selection model. Three features are worth noting. First, the Heckman estimates are biased. The bias of the Heckman estimate of β_1 ranges from -13% to 13% when zeros are few, and from 4% to 28% when zeros are many.

[49] In Appendix II, we conduct another set of experiments in which γ_1 is set to be negative. It turns out that the PPML estimates are biased downward.

The Heckman estimates of β_2 are also biased (although to a lesser degree). Second, the estimates from the Heckman model change drastically as the heteroskedastic pattern changes. This confirms that the logarithmic transformation imbedded in the Heckman procedure results in non-trivial biases. Therefore, the Heckman model is undesirable when heteroskedasticity is present. Thirdly, the variances of the Heckman estimate are very large, illustrating the identification problem caused by the Inverse Mill's Ratio. A glance at the E.T.-Tobit models reveals that the corresponding estimates are severely biased in most scenarios, as found in Silva and Tenreyro (2006).

Next, we discuss the performance of the proposed TS-NLS estimator. The TS-NLS estimate of β_1 is reasonably accurate, with the bias below 1% (2.5%) when zeros are few (many) across all scenarios of heteroskedasticity. The TS-NLS estimate of β_2 performs even better, evidenced by its small bias and variance in all cases. These findings confirm that the proposed TS-NLS estimator is capable of dealing with both heteroskedasticity and sample selection. Noticeably, under "many zeros" scenarios, the Truncated PPML model is slightly preferable over the TS-NLS model as far as bias is concerned. Nevertheless, according to the statistic of mean square error (which takes into account both bias and variance), the TS-NLS model remains the most suitable among all five estimators.

Several robustness checks are warranted before we close the section. One legitimate concern is about possible heteroskedasticity in the selection process. Since so far we have been dealing with heteroskedasticity in the outcome process, it can be asked if the TS-NLS estimator is robust to heteroskedasticity in the selection stage as well. To address this concern, we conduct another set of Monte-Carlo experiments in which we impose

$\sigma_{22i} = 1.43\exp(\gamma_1 x_{1i})$, so that the variance of the error term in the selection equation increases in its mean.[50] We re-estimate all the models and report the results in Table 2. Another issue worth considering is the assumption that the covariance of the two idiosyncratic terms is proportional to the mean of the outcome process. To examine to what extent the TS-NLS model is sensitive to this assumption, we generate new data by assuming a constant covariance, $\sigma_{12i} = 0.1$, and conduct all the estimation procedures again. The associated results are also reported in Table 2.

Table 2: Robustness checks in cases of many zeros (50%)

estimator	x	Check 1 Selection is heteroskedastic: Bias $\hat{\beta}-1$	Check 1: Var. $\mathrm{var}(\hat{\beta})$	Check 1: Mean Square Error	Check 2: Covariance is constant: Bias $\hat{\beta}-1$	Check 2: Var. $\mathrm{var}(\hat{\beta})$	Check 2: Mean Square Error
Homoskedasticity: the variance is a constant							
PPML	1	0.612	0.133	0.508	0.639	0.158	0.566
	2	0.003	0.004	0.004	-0.079	0.005	0.011
T-PPML	1	-0.022	0.010	0.010	-0.117	0.010	0.024
	2	0.000	0.000	0.000	-0.075	0.000	0.006
Heckman	1	0.057	29.02	29.02	0.157	8.800	8.825
	2	-0.315	56.35	56.45	0.108	4.089	4.101
Tobit	1	-0.254	2.145	2.209	-0.430	1.225	1.410
	2	-0.803	0.033	0.678	-0.849	0.024	0.744
TS-NLS	1	-0.027	0.003	0.003	-0.124	0.002	0.017
	2	0.000	0.000	0.000	-0.075	0.000	0.006
Heteroskedasticity: the variance is linear in the mean							
PPML	1	0.630	0.141	0.538	0.643	0.164	0.577
	2	0.001	0.004	0.004	-0.075	0.004	0.010
T-PPML	1	-0.026	0.011	0.012	-0.122	0.012	0.027
	2	0.001	0.000	0.000	-0.075	0.000	0.006
Heckman	1	-0.355	36.73	36.86	0.374	10.79	10.93
	2	0.150	27.80	27.82	0.075	1.392	1.398
Tobit	1	-0.130	2.952	2.969	-0.146	1.999	2.020
	2	-0.812	0.030	0.689	-0.825	0.031	0.711
TS-NLS	1	-0.027	0.005	0.006	-0.125	0.005	0.020
	2	0.001	0.000	0.000	-0.075	0.000	0.006

[50] We intentionally scale up the variance by a factor of 1.43 to ensure the new selection process is more noisy than in the benchmark.

Table 2. (continued)

estimator	x	Check 1 Selection is heteroskedastic			Check 2: Covariance is constant		
		Bias $\hat{\beta}-1$	Var. $var(\hat{\beta})$	Mean Square Error	Bias $\hat{\beta}-1$	Var. $var(\hat{\beta})$	Mean Square Error
Super-Heteroskedasticity: the variance is quadratic in the mean							
PPML	1	0.613	0.163	0.539	0.653	0.151	0.577
	2	-0.001	0.004	0.004	-0.075	0.004	0.010
T-PPML	1	-0.022	0.015	0.016	-0.110	0.018	0.030
	2	0.000	0.000	0.000	-0.075	0.000	0.006
Heckman	1	0.001	30.60	30.60	0.696	16.09	16.57
	2	2.179	5056	5060	0.029	1.756	1.757
Tobit	1	-0.016	2.911	2.911	-0.009	2.792	2.792
	2	-0.803	0.037	0.682	-0.815	0.030	0.695
TS-NLS	1	-0.026	0.008	0.009	0.120	0.007	0.021
	2	0.000	0.000	0.000	-0.075	0.000	0.006

Note: for succinctness, we only report the scenarios with 50% zeros.

We first discuss the cases with heteroskedasticity in the selection mechanism. As shown in Table 2, the performance of each estimator is qualitatively similar to the baseline cases in Table 1: the estimates from the PPML, the Heckman, and Tobit models are severely biased. The Truncated PPML and the TS-NLS estimators perform relatively well, with the magnitude of bias below 3%. In terms of mean square error, the TS-NLS model remains preferable over the Truncated PPML model because of the efficiency gain from accommodating zeros. Now we turn to the cases in which the covariance between the two error terms is constant. As shown in Table 2, such re-parameterization increases the biases of the TS-NLS estimates to 12% for β_1 and 8% for β_2. The reason is the conditional mean in the second stage of the TS-NLS model, (4c), is not correctly specified when the covariance is not proportional to the mean. Nevertheless, the TS-NLS model still dominates all other four estimators according to the mean square error criteria. Therefore, we conclude from the current section that the TS-NLS model strictly dominates the PPML, the Heckman, and the

E.T.-Tobit models, and that it weakly outperforms the Truncated PPML model in terms of the estimation of the intensive margin.

An Empirical Application

In this section, we illustrate our proposed TS-NLS procedure with an investigation of the impact of various trade costs on world trade in 1986. In terms of the choice of estimator, we apply the proposed Two-Step Nonlinear Least Square (TS-NLS) estimator, along with the (PPML) estimator, the Heckman sample selection model, and the E.T.-Tobit model. The comparison across models suggests that the both statistical and economic inferences are sensitive to the choice of the estimation method. Several diagnostic tools further demonstrate the capability of the TS-NLS model for the estimation of a gravity equation model in the presence of heteroskedasticity and frequent zeros.

The Data

Drawn from Helpman, Melitz, and Rubinstein (2008), the data cover bilateral trade flows among 158 countries in 1986.[51] The trade determinants of interest include the geographic distance, the common border dummy variable, the island dummy variable, the landlocked dummy variable, the historical tie, the currency union dummy variable, the common legal system dummy variable, the common religion variable, and the Free Trade Agreement (FTA) dummy variable. Table 3 provides the definitions and summary statistics of the variables. Noticeably, more than half of the trade flows are recorded as zeros, which calls for careful treatment when it comes to statistical estimation. In addition, a cross-sectional sample

[51] Although the original data in Helpman, Melitz, and Rubinstein (2008) covers 1980-1989, their main results are based on the analysis of the 1986's cross-section. Another reason for using a cross-sectional dataset is that the associated results are more comparable to those obtained in Silva and Tenreyro (2006), in which a snap-shot of the world trade in 1990 was considered.

comprising a large set of heterogeneous countries may give rise to a considerable degree of heteroskedasticity. Therefore, the data set serves well as an example of a gravity equation model in which both the prevalence of zeros and the possibility of heteroskedasticity should be satisfactorily dealt with.

Table 3: Variable definition and summary statistics

Variable	Definition	mean	st. dev.	min	max
$trade_{ij}$ [a,b]	country j's import from country i	8348.5	1075389	0	8.7e+7
$dist_{ij}$	log-scaled distance between country i and j	4.18	0.78	-0.15	5.66
$religion_{ij}$	see note c for the definition	0.18	0.25	0	0.999
$border_{ij}$	Dummy variable that equals 1 if country i and j are adjacent	0.02	0.13		
$island_{ij}$	Dummy variable that equals 1 if either country i or j belongs to an island	0.37	0.48		
$landlock_{ij}$	Dummy variable that equals 1 if either country i or j is landlocked	0.27	0.44		
$colony_{ij}$	Dummy variable that equals 1 if country i or j had a colonial tie	0.01	0.10		
$language_{ij}$	Dummy variable that equals 1 if country i or j use the same official language	0.29	0.45		
cu_{ij}	Dummy variable that equals 1 if country i and j use the same currency	0.01	0.10		
$legal_{ij}$	Dummy variable that equals 1 if country i and j have the same legal system	0.37	0.48		
FTA_{ij}	Dummy variable that equals one if country i and j belong to a regional trade agreement.	0.01	0.08		

Note: a. The number of observation is 24806(=158*157); b. The percentage of zero trade flows is 55.1%. c. % of Protestants in country i * % of Protestants in country j + % of Catholics in country i * % of Catholics in country j + % of Muslims in country i * % of Muslims in country j.

Results and Discussions

We apply the PPML, the Truncated PPML, the Heckman sample selection, the E.T.-Tobit, and the TS-NLS estimators to the data and discuss how different methods of estimation change the statistical and economic inferences. From the gravity equation framework, we expect bilateral trade to be smaller if the two countries are further apart, or one of them is isolated in an island, or one of them has no costal lines. On the other hand, we speculate that scale of trade is larger if the two countries are adjacent, or had a colonial relationship in history, or adopt the same legal or currency system, or share common religious beliefs, or engage in a regional trade agreement. The econometric results associated with all five estimators are presented in Table 4.

Table 4. Results of the PPML, Heckman, E.T.-Tobit, and TS-NLS models

	Heckman	E.T.-Tobit	PPML	PPML>0	TS-NLS	
					Probit	NLS
$dist_{ij}$ [a]	-1.21***	-1.21***	-0.64***	-0.64***	-0.01***	-0.68***
	(0.03)	(0.03)	(0.04)	(0.04)	(0.00)	(0.05)
$religion_{ij}$	excluded[b]	0.34***	-0.23**	-0.08	0.37***	-0.44***
		(0.07)	(0.11)	(0.11)	(0.06)	(0.13)
$border_{ij}$	0.44***	0.02	0.72***	0.73***	0.30***	0.62***
	(0.12)	(0.15)	(0.11)	(0.11)	(0.09)	(0.11)
$island_{ij}$	-0.42***	-0.55***	0.38**	0.41**	-0.43***	0.33
	(0.11)	(0.09)	(0.19)	(0.19)	(0.08)	(0.21)
$landlock_{ij}$	-0.57***	-0.49***	-0.57***	-0.56***	-0.23**	-0.69***
	(0.16)	(0.13)	(0.21)	(0.21)	(0.10)	(0.23)
$colony_{ij}$	1.31***	1.17***	0.35***	0.36***	0.28	0.32**
	(0.13)	(0.11)	(0.12)	(0.11)	(0.26)	(0.14)
$language_{ij}$	0.22***	0.43***	-0.18**	-0.16*	0.31***	-0.04
	(0.05)	(0.05)	(0.09)	(0.09)	(0.04)	(0.09)
cu_{ij}	1.39***	1.19***	0.58	0.46	0.78***	0.94
	(0.21)	(0.19)	(0.44)	(0.44)	(0.12)	(0.60)
$legal_{ij}$	0.49***	0.33***	0.31***	0.28***	0.06**	0.29***
	(0.04)	(0.04)	(0.06)	(0.06)	(0.03)	(0.07)
FTA_{ij}	0.74***	0.61***	0.23***	0.26***	1.99***	0.12
	(0.16)	(0.20)	(0.08)	(0.08)	(0.25)	(0.08)

Table 4. (continued)

	Heckman	E.T.-Tobit	PPML	PPML>0	TS-NLS	
					Probit	NLS
IMR_{ij} [c]	0.26*** (0.06)	n.a.	n.a.	n.a.	n.a.	3.37*** (1.09)
fixed effects [d]	yes	yes	yes	yes	yes	yes

Note: a. In the Probit model, the distance variable is expressed in levels, instead of logs, to help with the identification in the second stage; b. Following HMR, the religion variable is excluded from the second-stage of the Heckman procedure; c. Inverse Mill's Ratio is calculated from the first-stage Probit model; d. fixed effects are dummy variables for each importer and each exporter. *, **, and *** denote the significance level at 10%, 5%, and 1% respectively.

The results from the Heckman sample selection model are presented in the second column of Table 4. Qualitatively, the Heckman results are similar to those reported in Helpman, Meltiz, and Rubinstein (2008) in which the effect of the number of exporting firms is controlled for.[52] In fact, the effects of all trade determinants bear the expected signs and are statistically significant. Moreover, the Inverse Mill's Ratio is highly significant, implying that the sample selection is indeed non-random in this current study. The results from the E.T.-Tobit model are reported in the third column of Table 4. In terms of the signs of estimated coefficients and significant levels, the E.T.-Tobit model yields similar inferences as in the Heckman model, except that the border effect becomes insignificant in the E.T.-Tobit model. The similarity between the Heckman and E.T.-Tobit results is partly attributable to their similarity in the underlying assumptions. Specifically, both the Heckman model and the E.T.-Tobit model consider zero trade flows as countries' inability to trade: the former achieves the goal by adding a selection process, while the latter allows trade records to be censored once they are below a minimal threshold. However, both models are likely to

[52] We do not account for the number of exporting firms because such new firm's margin is often mis-specified in the presence of heteroskedasticity (Silva and Tenreyro, 2009). Nevertheless, the Heckman model generates similar inferences on all trade cost terms except for the island dummy variable (whose effect changes from negative and statistically insignificant in HMR to negative and statistically significant in Heckman) and the common language dummy variable (whose effect changes from statistically insignificant in HMR to positive and statistically significant in Heckman).

deliver biased estimates in the presence of heteroskedasticity because of the logarithmical linearization of the gravity equation.

Column 4 and 5 of Table 4 present the results from the PPML model and the Truncated PPML model respectively. As shown in column 4 of Table 4, the trade effects of some variables in the PPML model turn out counter-intuitive. For example, the impact of common religion or common language is estimated to be negative and statistically significant, but belonging to an island somehow promotes trade in a statistical significant way. A glance at the column 5 of Table 4 reveals that moving to the Truncated PPML model alleviates some but not all the puzzles. Such unexpected results delivered by the PPML and Truncated PPML models cast doubt on their underlying assumptions. In other words, the issue of non-random sample selection should not be ignored for the current study.

We now turn to the TS-NLS model. The first-step Probit estimation is summarized in second last column of Table 4. All trade determinants carry the expected signs and are statistically significant except for the colonial tie dummy variable. The second-step Nonlinear Least Square estimation is presented in the last column of Table 4. Three features are worth noting here. First, the Inverse Mill's Ratio is highly significant, pointing to the importance of correcting for the sample selection bias. Second, the common religion variable turns out adversely affecting the amount of trade between actively trading countries. Later we will show that this negative effect on the intensive margin is more than offset one the impact on the extensive margin is taken into account. Thirdly, the positive effects of common currency and regional trade agreements do not stand out statistically significant in the second stage, suggesting that both factors may play a more important role in facilitating the creation of new trade partnership, than in increasing the pre-existing trade volumes.

To put the econometric results in Table 4 into a richer economic context, we compute the marginal effects in each model and present them in Table 5. It is clear from Table 5 that different methods of estimation yield different marginal effects, either on the intensive margin or on the extensive margin, which echoes Linders and Groot (2011). We mainly discuss the marginal effects generated from the TS-NLS model. A longer distance reduces both the propensity to trade and the volume of trade, with an overall elasticity of -1.48(=-1.04-0.68+0.24).[53] The net effect of the similarity of religion is positive (0.47-0.44+0.15=0.18), although it affects the two margins in opposite directions. A plausible explanation is that new entrants to the world market (corresponding to the positive effect on the extensive margin) tend to "steal business" from the incumbent exporters (leading to a negative effect on the intensive margin). A shared country border, a historical colonial relationship, a common official language, or a shared legal system facilitates trade as expected. Being isolated in an island or having no coastal lines constrains trade, which is in line with our presumptions.

Table 5: Marginal effects of Heckman, E.T.-Tobit, and TS-NLS models[a]

	Heckman[b]	E.T.-Tobit		TS-NLS		
	intensive	extensive	intensive	extensive	Intensive[c]	
					direct	indirect
$dist_{ij}$	-1.11	-1.38	-2.93	-1.04	-0.68	0.24
	(0.03)	(0.05)	(0.07)	(0.05)	(0.05)	(0.03)
$religion_{ij}$	n.a.	0.39	0.83	0.47	-0.44	0.15
		(0.09)	(0.17)	(0.07)	(0.13)	(0.02)
$border_{ij}$	0.50	0.02	0.04	0.38	0.62	-0.22
	(0.12)	(0.19)	(0.35)	(0.12)	(0.11)	(0.03)
$island_{ij}$	-0.37	-0.62	-1.33	-0.54	0.33	-0.12
	(0.11)	(0.12)	(0.21)	(0.10)	(0.21)	(0.02)
$landlock_{ij}$	-0.54	-0.55	-1.18	-0.29	-0.69	0.24
	(0.16)	(0.18)	(0.32)	(0.12)	(0.23)	(0.03)

[53] The magnitude is within the range reported by Disdier and Head (2008).

Table 5. (continued)

	Heckman[b]	E.T.-Tobit		TS-NLS		
	intensive	extensive	intensive	extensive	Intensive[c]	
					direct	indirect
$colony_{ij}$	1.26	1.33	2.82	0.36	0.32	-0.11
	(0.13)	(0.15)	(0.27)	(0.33)	(0.14)	(0.02)
$language_{ij}$	0.18	0.48	1.03	0.40	-0.04	0.01
	(0.05)	(0.06)	(0.11)	(0.05)	(0.09)	(0.00)
cu_{ij}	1.32	1.35	2.88	0.98	0.94	-0.33
	(0.21)	(0.27)	(0.50)	(0.15)	(0.60)	(0.05)
$legal_{ij}$	0.48	0.37	0.80	0.08	0.29	-0.10
	(0.04)	(0.05)	(0.09)	(0.04)	(0.07)	(0.01)
FTA_{ij}	0.44	0.69	1.46	2.51	0.12	-0.04
	(0.16)	(0.25)	(0.47)	(0.32)	(0.08)	(0.01)

Note: a. The marginal effects of the PPML are omitted because they are identical to the corresponding raw coefficients reported in column 4 and 5 of Table 4. b. The extensive margins from the Heckman model is omitted because they are identical to the extensive margins from the TS-NLS model. c. The intensive margin is further decomposed into two parts: the direct effect corresponds to the raw coefficients in the second stage; the indirect effect is through the sample selection correcting term.

Interestingly, the adoption of the same currency or the engagement in a regional trade agreement is found to foster bilateral trade, but such trade-promoting effect is only significant through the extensive margin. In other words, both factors are more likely to improve market access and induce more countries to start trading, than to expand the size of trade between countries that have been trading all along. The mild effect of FTAs on the intensive margin to trade has been found in previous studies as well. Specifically, Rose (2004) reported that the GATT/WTO membership (which can be seen as a broadly defined multilateral FTA) does not play a strong role in expanding the amount of trade. Felbermayr and Kohler (2007) argued that the WTO membership promotes international trade primarily via the extensive margin.[54] The literature also provides several studies in support of the limited positive effect of the currency union on the intensive margin to trade. In particular,

[54] However, Baier and Bergstrand (2007) argue that the trade effect of FTAs is under-estimated due to the endogeneity problem.

Rose and van Wincoop (2001) show that the trade-promoting effect of monetary union is generally over-estimated. Using a dataset exclusive of zero trade records, Baldwin and Taglioni (2006) report that the impact of currency union on international trade is trivial.

Diagnostic Analysis

As shown in Section 3, the TS-NLS estimator outperforms the alternative estimators in a gravity equation analysis because it satisfactorily deals with heteroskedasticity and addresses the sample selection bias. In this subsection, we propose a model selection strategy for the empirical application and evaluate the suitability of each estimator.

We select the appropriate model based on two criteria. The first consideration is the correct specification of the regression equation. If the regression equation is mis-specified, the corresponding estimates are inconsistent. We use the Reset specification test (Ramsey, 1969) as a diagnostic tool for this purpose. Intuitively, the test is implemented by fitting the regression equation with one additional regressor that is the square of the linear prediction generated from the original specification. The null hypothesis that the original specification is correctly specified is rejected if the additional regressor turns out statistically significant. Table 6 summarizes the test results for all estimators. The Heckman model and the E.T.-Tobit model are found to be mis-specified, which confirms that the practice of logarithmic transformation is inappropriate. In contrast, the PPML model (or its truncated version) and the TS-NLS model, both expressing trade flows in levels, survive the specification test.[55] Our second model selection criterion is to compare the predicted with the observed trade flows.[56]

[55] We also conduct the Reset test for the first-stage Probit of the TS-NLS model and find weak evidence of mis-specification: the null hypothesis is rejected at 10% and 5% level, but accepted at 1% level.
[56] In the Heckman and the TS-NLS models, trade is predicted to be zero if the associated fitted probability of trading is less than 0.5.

To examine the accuracy of prediction of each estimator, we compute the correlation between the predicted and observed outcomes and report them in the bottom half of Table 6. As shown in the table, the PPML, the Truncated PPML, and the TS-NLS models predict trade flows reasonably well, with the correlations above 0.9. As expected, the prediction from the Heckman model or the E.T.-Tobit model is much less accurate. Therefore, given the specification test results and the correlation analysis, we consider the Heckman model and the E.T.-Tobit model strongly dominated, and the Truncated PPML weakly dominated (by the TS-NLS model).

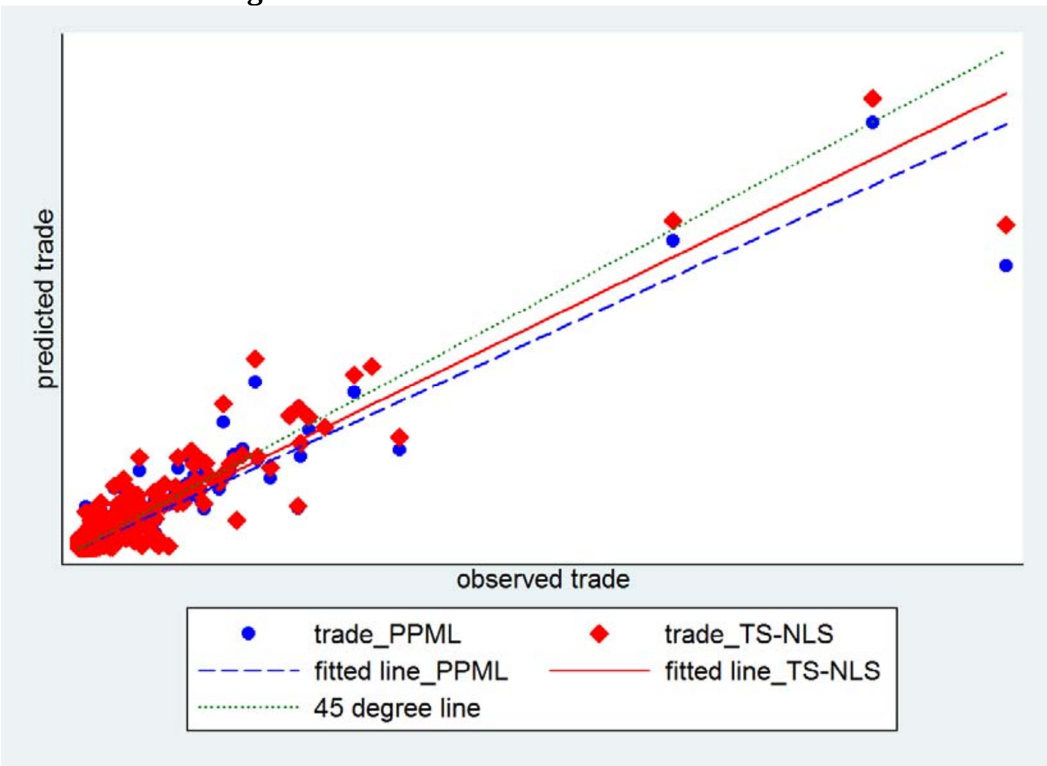
Table 6: Specification test and correlation of observed and predicted trade

P value of the Reset test[a]	Heckman	E.T.-Tobit	PPML	PPML>0	TS-NLS
	0.00	0.00	0.51	0.65	0.45
Correlation with observed trade	Heckman	E.T.-Tobit	PPML	PPML>0	TS-NLS
	0.594	0.600	0.939	0.936	0.942

Note: a. Reset test is conducted as follows: (i) re-estimate the model with an auxiliary variable, which is the square of the linear prediction from the original specification; (ii) test if the auxiliary variable is statistically different from zero; (iii) the original specification is mis-specified if the null hypothesis in (ii) is rejected.

Now that the model selection boils down to the comparison between the PPML model and the TS-NLS model, we push our second criterion further by regressing the predicted trade series on the actually observed trade series. In Figure 1, we depict the two fitted lines and compare them with the 45 degree diagonal (corresponding to perfect prediction). It is clear from Figure 1 that the fitted line associated with the TS-NLS model is closer to the 45 degree diagonal than the fitted line associated with the PPML model. Therefore, we conclude from our model selection strategy that the TS-NLS model is the most preferred model for this particular empirical study.

Figure 1. Predicted trade and observed trade



Conclusion

A vexing issue in the gravity equation model to trade is how to statistically estimate the model when two stylized features are present in trade data: numerous zero trade records and heteroskedasticity. In this paper, we answer the question by proposing a Two-Step Nonlinear Least Square (TS-NLS) estimator. The novel estimator works as follows. In the first step, the estimator characterizes the binary decision to trade and shed light on the extensive margins to trade. In the second step, positive trade flows are estimated in levels via a weighted nonlinear least square procedure, with the potential sample selection bias taken into account. Consequently, the estimator yields consistent estimates for the structural parameters in a gravity equation and identifies the extensive margin of trade from the intensive margins of trade. In a set of Monte-Carlo experiments, we show that the TS-NLS estimator strictly dominates the PPML model, the Heckman model, and the E.T.-Tobit model, and that it weakly outperforms the Truncated PPML model. In an analysis of world trade and its determinants in 1986, we further illustrate the usefulness of the TS-NLS model. We find that the adoption of the same currency and the participation in a regional trade agreement facilitate trade primarily via improving market access for previous non-traders, rather than expanding the size of existing trade between active traders.

Several extensions can be attempted to fully utilize the proposed TS-NLS estimator. For example, it is desirable to relax the joint normality assumption and address the issue of non-random sample selection in a more general way. It is also interesting to apply the TS-NSL model to other constant-elasticity economic models. For example, one may expect certain degree of heteroskedasticity in wages or earnings data. Therefore, it is worthwhile to estimate the Mincer log earnings model (Mincer, 1974) via the TS-NLS procedure and investigate to what extent the logarithmic transformation biases the results.

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Appendix

Table A. Simulation results under six scenarios when $\gamma_1 = -1$

estimator	x	Few zeros (20%) Bias $\beta - 1$	Few zeros (20%) Var. $var(\hat{\beta})$	Few zeros (20%) Mean Square Error	Many zeros (50%) Bias $\beta - 1$	Many zeros (50%) Var. $var(\hat{\beta})$	Many zeros (50%) Mean Square Error
Homoskedasticity: the variance is a constant							
PPML	1	-0.318	0.037	0.138	-0.789	0.148	0.770
	2	-0.001	0.001	0.001	-0.002	0.005	0.005
T-PPML	1	0.018	0.002	0.002	0.019	0.007	0.007
	2	0.000	0.000	0.000	0.000	0.000	0.000
Heckman	1	0.165	3.130	3.157	0.315	13.93	14.03
	2	0.029	1.474	1.475	-0.061	15.11	15.11
Tobit	1	-0.622	0.994	1.381	-0.954	1.620	2.530
	2	-0.696	0.065	0.550	-0.814	0.032	0.695
TS-NLS	1	0.014	0.002	0.002	0.021	0.002	0.003
	2	0.000	0.000	0.000	0.000	0.000	0.000
Heteroskedasticity: the variance is proportional to the mean							
PPML	1	-0.346	0.040	0.160	-0.802	0.155	0.798
	2	-0.001	0.001	0.001	0.002	0.004	0.004
T-PPML	1	0.016	0.003	0.004	0.013	0.019	0.019
	2	0.000	0.000	0.000	0.000	0.000	0.000
Heckman	1	0.053	3.216	3.219	0.035	17.10	17.10
	2	-0.032	1.855	1.856	0.163	12.71	12.74
Tobit	1	-0.463	1.112	1.326	-0.888	1.141	1.930
	2	-0.626	0.079	0.471	-0.833	0.024	0.718
TS-NLS	1	0.007	0.003	0.004	0.018	0.005	0.006
	2	0.000	0.000	0.000	0.000	0.000	0.000
Super-Heteroskedasticity: the variance is proportional to the squared mean							
PPML	1	-0.346	0.041	0.160	-0.795	0.168	0.800
	2	-0.001	0.001	0.001	0.000	0.005	0.005
T-PPML	1	0.017	0.006	0.006	0.013	0.018	0.018
	2	0.000	0.000	0.000	0.000	0.000	0.000
Heckman	1	-0.029	3.251	3.251	0.179	24.48	24.51
	2	-0.039	1.585	1.587	0.005	1.001	1.002
Tobit	1	-0.544	0.837	1.133	-0.840	1.409	2.115
	2	-0.637	0.083	0.488	-0.815	0.028	0.692
TS-NLS	1	0.006	0.006	0.006	0.016	0.008	0.008
	2	0.000	0.000	0.000	0.000	0.000	0.000