PISSN 2508-1640 EISSN 2508-1667 an open access journal
East Asian Economic Review vol. 21, no.4 (December 2017) 295-315
http://dx.doi.org/10.11644/KIEP.EAER.2017.21.4.332

Gravity with Intermediate Goods Trade*

Sujin Jang
Metro Seoul
wkdtn8733@gmail.com

E. Young Song†
Department of Economics
Sogang University
eysong@sogang.ac.kr

This paper derives the gravity equation with intermediate goods trade. We extend a standard monopolistic competition model to incorporate intermediate goods trade, and show that the gravity equation with intermediates trade is identical to the one without it except in that gross output should be used as the output measure instead of value added. We also show that the output elasticity of trade is significantly underestimated when value added is used as the output measure. This implies that with the conventional gravity equation, the contribution of output growth can be substantially underestimated and the role of trade costs reduction can be exaggerated in explaining trade expansion, as we demonstrate for the case of Korea's trade growth between 1995 and 2007.

Keywords: Gravity Equation, Gross Output, Intermediate Goods Trade, Global Value Chains, Fragmentation
JEL Classification: F12, F14, F15

I. INTRODUCTION

Last several decades saw a huge increase in the trade of intermediate goods across countries. This phenomenon was driven by the rise of global supply chains, also called by various other names, such as fragmentation, unbundling, or vertical

* This paper is developed from Jang (2014). Song gratefully acknowledges the financial support from Sogang University under the Research Grant of 201310029.01. The authors are grateful to three anonymous referees for their comments, which substantially improved the paper. However, all remaining errors are ours.

† Corresponding author.

specialization of production. A production process is broken into a number of parts, which then are relocated in various countries of the world. As a result, unfinished products cross borders multiple times before they reach a final user, and trade volume increases relative to value added produced by trade.

The new aspect of world trade can be understood by investigating world input-output tables or analyzing a computable general equilibrium model embodying worldwide input-output structure. Hummels, Ishii and Yi (2001), Yi (2003), Johnson and Noguera (2012), Bridgman (2012), and Koopman, Wang and Wei (2014) are notable examples in this line of research.

An alternative approach is to modify the gravity equation to encompass intermediate goods trade. The gravity equation states that bilateral trade is proportional to the product of the masses of trading pairs, and is inversely related to trade costs between them. It has been the most powerful and popular tool for estimating the determinants of bilateral trade flows. The gravity model gained more traction in recent years since Eaton and Kortum (2002), Anderson and van Wincoop (2003), and Chaney (2008) strengthened its theoretical foundation by rigorously deriving it from muti-country Ricardian, Chamberlinian, and heterogeneous firms trade models.

Modifying the gravity equation to incorporate intermediates trade should start from a simple observation that trade is measured in gross sales, while GDP is measured in value added. Most theoretical studies on the gravity equation assume the world without intermediates goods, and thus ignore the difference between gross sales and value added. Most empirical studies estimating the gravity equation use GDP to measure the mass of a country, either because trade theories ignoring the presence of intermediate goods justify its use, or because data on gross output are not easily available. However, one can conjecture that to obtain reliable results, either trade in terms of value added should be regressed on value added output, or trade in gross sales should be regressed on gross output. The former approach, as exemplified by Aichele and Heiland (2014), would require a complicated task of collapsing the inverse matrix coefficients of input-output tables into a manageable number of explanatory variables. Reduced gravity equations would be model-specific or their coefficients would be difficult to link to structural parameters.

In this paper, we take the latter approach of explaining gross trade by gross output. A number of researchers have estimated the gravity equation by regressing gross trade on gross output because it made more intuitive sense (e.g., Wei, 1996 and Novy, 2013). However, they do not offer any theoretical justification. The paper by Baldwin and Taglioni (2011), to our knowledge, is the first study that formally derives the gravity equation with intermediate goods trade, and emphasizes the importance of using gross output as the mass variable. We build upon their results, and show that the mass variable of the gravity equation with intermediated goods trade should be gross output for the exporter, and gross output plus net imports for the importer.[1] We derive this result in a general setting where the ratio of value added to gross output responds to economic variables such that using value added as the mass variable generates errors-in-variables bias. Most trade models with intermediate goods (e.g., Krugman and Venables, 1996; Eaton and Kortum, 2002; Baldwin and Taglioni, 2011) assume that the production function for gross output is of Cobb-Douglas, and thus the ratio of value added to gross output is fixed. Under this assumption, value added is a perfect proxy for gross output, and the question that we raise in this paper becomes meaningless.

A convenient feature of our gravity equation is that it holds both for aggregate trade and for sectoral level trade. A number of empirical studies on gravity estimate the gravity equation at sectoral level. Some studies aim to demonstrate that the elasticity of trade with respect to output, trade costs, or exchange rate volatility varies depending on the nature of goods, while others try to capture a trade pattern specific to an industry. Rauch (1999), Feenstra et al. (2001), Evans (2003), Saito (2004), Baldwin et al. (2005), and Anderson et al. (2014) are just a few such examples. In this line of research, it has never been entirely clear which mass variable should be used for the exporter and which for the importer. This paper provides a rigorous answer to this question.

In addition, this paper tests whether the use of gross output as the mass variable improves the performance of the gravity equation over the popular practice of using value added as the mass variable. Baldwin and Taglioni (2011) also conduct a similar comparison. Because data on gross output are not widely available, they suggest using the sum of GDP and intermediate goods trade as a proxy, and show that the proxy performs better than GDP in gravity equation estimations. In this paper, we use gross output data from the World Input-Output Table (Timmer et al.,

[1] Baldwin and Taglioni (2011) show that the mass variable for the exporter should be gross output, as we confirm here, and the one for the importer should be GDP plus the total costs of production, which is different from ours. In addition, we derive the gravity equation that holds both for aggregate trade and for sectoral level trade under a more general setting.

2015), and explicitly show that fluctuations in gross output to value added ratio generate downward bias in the estimation of the mass variable coefficient when value added is used as the mass variable. This implies that if we use the conventional gravity equation with value added as the mass variable, the contribution of output growth can be substantially underestimated, and the role of trade costs reduction can be significantly exaggerated in explaining trade expansion. We demonstrate this possibility using the case of Korea’s trade growth between 1995 and 2007.

This paper is organized as follows. In section II, we derive the gravity equation in the presence of intermediate goods trade from a monopolistic competition model with intermediate goods trade. In section III, we estimate the gravity equation, and compare the empirical performance of value added and gross output as the mass variable. Section III briefly concludes this paper.

II. THEORY

To introduce intermediate goods trade into the gravity theory, we utilize the framework used by Krugman and Venables (1996), Eaton and Kortum (2002), and Baldwin and Taglioni (2011). The essence of the idea is the assumption that each firm produces a good (or a service) that can be used both as an intermediate good and as a final good. We incorporate the idea into the monopolistic competition model by Krugman (1979) and Anderson and van Wincoop (2003), where all firms located in the same country are assumed to be symmetrical.

There are K industries in the world. Goods produced in industry m are differentiated from each other and indexed on an interval N^m. Each firm produces only one good so that we can index firms by the index of goods. Firms located in country i produces a subset of N^m, and let n_i^m be its measure. Free entry prevails everywhere and the profit of each firm is equal to zero.

To produce q units of an industry m good in country i, $f_i^m + a_i^m q$ units of Z_i^m are required. f_i^m is the fixed cost of production, and a_i^m is the marginal cost, both measured in the unit of Z_i^m. Z_i^m is a composite good, which is produced by a CES production function using local labor L_i^m and composite intermediate goods G_i^{mk} $(k = 1, \ldots, K)$:

$$Z_i^m = \left[(\alpha^{mL})^{\frac{1}{\varepsilon^m}} (L_i^m)^{\frac{\varepsilon^m - 1}{\varepsilon^m}} + \sum_{k=1}^{K} (\alpha^{mk})^{\frac{1}{\varepsilon^m}} (G_i^{mk})^{\frac{\varepsilon^m - 1}{\varepsilon^m}}\right]^{\frac{\varepsilon^m}{\varepsilon^m - 1}}, \tag{1}$$

ε^m is the elasticity of substitution among labor and composite inputs, and is assumed to be greater than one. G_i^{mk}, composite intermediate good k used in industry m of country i, in turn, is made by assembling industry k goods produced all over the world.

$$G_i^{mk} = \left[\int_{s \in N^k} g_i^m(s)^{\frac{\sigma^k - 1}{\sigma^k}} ds\right]^{\frac{\sigma^k}{\sigma^k - 1}}. \tag{2}$$

$g_i^m(s)$ $(s \in N^k)$ is the input of an industry k good into composite intermediate good G_i^{mk}. σ^k is the elasticity of substitution between g_i^m's, and is greater than one. We assume that individual goods entering composite intermediate goods are tradable, but composite goods themselves are not tradable. Equation (2) implicitly assumes that σ^k does not depend on m, the industry that uses intermediate inputs. As we will see soon, this is a crucial assumption.

The unit cost of G_i^{mk} is given by the following price index:

$$P_i^k = [\int_{s \in N^k} (p_i(s))^{1-\sigma^k} ds]^{\frac{1}{1-\sigma^k}}. \tag{3}$$

$p_i(s)$ is the price of good s in country i. Denoting the wage rate in country i by W_i, using (1), the unit cost of Z_i^m can be written as:

$$V_i^m = \left[\alpha^{mL}(W_i)^{1-\varepsilon^m} + \sum_{k=1}^{K} \alpha^{mk} (P_i^k)^{1-\varepsilon^m}\right]^{\frac{1}{1-\varepsilon^m}}. \tag{4}$$

Thus the total cost of a country i firm producing q units of an industry m good is given by:

$$C_i^m = (f_i^m + a_i^m\, q)\, V_i^m. \tag{5}$$

Denoting the marginal cost by c_i^m,

$$c_i^m = \; a_i^m\, V_i^m. \tag{6}$$

Applying Shephard's lemma to (4), we can obtain the shares of labor and composite intermediate goods in the total cost of a country i firm in industry m:

$$\gamma_i^{mL} \equiv \frac{W_i\, L_i^m}{C_i^m} \;= \alpha^{mL} \left(\frac{W_i}{V_i^m}\right)^{1-\varepsilon^m} \quad , \tag{7}$$

$$\gamma_i^{mk} \equiv \frac{P_i^k\, G_i^{mk}}{C_i^m} \;= \alpha^{mk} \left(\frac{P_i^k}{V_i^m}\right)^{1-\varepsilon^m} \quad . \tag{8}$$

Using (3), (4), and (8), we can derive the value of good s that enters composite intermediate good k used in industry m of country i.

$$p_i(s)\, g_i^m(s) \; = \left(\frac{p_i(s)}{P_i^k}\right)^{1-\sigma^k} \gamma_i^{mk}\, C_i^m \;\text{ for }\; s \in N^k. \tag{9}$$

The representative household in country i maximizes the following utility function.

$$U_i = \left[\sum_{k=1}^{K} \left(\alpha^{hk}\right)^{\frac{1}{\varepsilon^h}} \left(G_i^{hk}\right)^{\frac{\varepsilon^h-1}{\varepsilon^h}}\right]^{\frac{\varepsilon^h}{\varepsilon^h-1}}. \tag{10}$$

Here, superscript h denotes the household, and G_i^{hk} is composite good k consumed by the household as a final good. Again, it is made of industry k goods produced all over the world:

$$G_i^{hk} = \left[\int_{s\in N^k} g_i^h\,(s)^{\frac{\sigma^k-1}{\sigma^k}}\,ds \right]^{\frac{\sigma^k}{\sigma^k-1}}. \quad (11)$$

Composite final good k is assumed to be made in the same way as composite intermediate good k used by industries. Equation (10) assumes that no direct labor is used to produce household utility. This restriction is not necessary, but we adopt it as it conforms to the structure of input-output tables.

Using the same method as before, we can show that

$$p_i(s)\; g_i^h(s) \;= \left(\frac{p_i(s)}{P_i^k}\right)^{1-\sigma^k} \gamma_i^{hk}\, E_i \;\text{ for }\; s \in N^k. \quad (12)$$

E_i is the final expenditure of a country *i*, and is equal to its GDP plus its net imports. γ_i^{hk} is the share of composite good k in final expenditure, and is given by

$$\gamma_i^{hk} \equiv \frac{P_i^k\; G_i^{hk}}{E_i} \;= \alpha^{hk}\left(\frac{P_i^k}{V_i^h}\right)^{1-\varepsilon^h}, \quad (13)$$

$$V_i^h = \left[\sum_{k=1}^{K} \alpha^{hk}\left(P_i^k\right)^{1-\varepsilon^h}\right]^{\frac{1}{1-\varepsilon^h}}. \quad (14)$$

To maximize the profit, a firm sets its price as a markup over the marginal cost, the markup rate determined by the price elasticity of its demand. By CES demand functions given in (9) and (12), the price elasticity for an industry k good is given by σ^k. Thus,

$$p_{ij}^k = \tau_{ij}^k \frac{\sigma^k}{\sigma^k-1}\, c_i^k\,. \quad (15)$$

p_{ij}^k is the price of an industry k good produced in country *i* and sold in country *j*. Here τ_{ij}^k (≥ 1) represents an iceberg-type transportation cost, and a firm in country

i has to produce τ_{ij}^k units of a good to sell one unit in country j. Note that $p_j(s) = p_{ij}^k$ if $s \in N^k$ and s is produced in country i.

By (9)and (12), the value of good s produced in industry k of country i and sold in country j, both as an intermediate good and as a final good, is determined by:

$$x_{ij}(s) = \left(\frac{p_{ij}^k}{P_j^k}\right)^{1-\sigma^k} \left(\sum_{m=1}^{K} \gamma_j^{mk} n_j^m C_j^m + \gamma_j^{hk} E_j\right). \tag{16}$$

Equation (16) is crucial for our result below. The essential feature of the equation that allows the gravity equation to follow from it is that demand for good s in country j is mutiplicatively separable between relative price $\left(p_{ij}^k / P_j^k\right)^{1-\sigma^k}$ and total expenditure on good $\left(\sum_{m=1}^{K} \gamma_j^{mk} n_j^m C_j^m + \gamma_j^{hk} E_j\right)$. This property, in turn, follows from our assumption that composite input Z^m for producing an industry m good is produced by a nested CES function of subinputs G^{mk}'s given in (1), and the additional assumption that σ^k, the elasticity of substitution between individual industry k goods in the production of subinput G^{mk}, does not depend on m, as assumed in (2).

The rest of derivation is straightforward. Because $x_{ij}(s)$ is identical for all industry k firms in country i, the total value of industry k goods exported from country i to country j is equal to:

$$X_{ij}^k = n_i^k \left(\frac{p_{ij}^k}{P_j^k}\right)^{1-\sigma^k} \left(\sum_{m=1}^{K} \gamma_j^{mk} n_j^m C_j^m + \gamma_j^{hk} E_j\right). \tag{17}$$

From the assumption that the profit of each firm is zero, the total costs incurred by industry m firms in country j $(n_j^m C_j^m)$ is equal to the gross output of industry m in country j, which we denote by GO_j^m. Then we can show that:

$$\sum_{m=1}^{K} \gamma_j^{mk} n_j^m C_j^m + \gamma_j^{hk} E_j = GO_j^k + IM_j^k - EX_j^k \, . \tag{18}$$

Equation (18) is an accounting identity that holds in any input-output model: the total value of industry k goods used in a country, both as intermediates and final goods, must be equal to the total value of industry k goods supplied to the country, which is equal to their domestic production (GO_j^k) plus their imports (IM_j^k) minus their exports (EX_j^k). To see this more formally, we divide γ_j^{mk} into two parts: the share of domestically produced goods γ_j^{mkd} and the share of imported goods γ_j^{mkf}. $\gamma_j^{mk} = \gamma_j^{mkd} + \gamma_j^{mkf}$. Likewise, $\gamma_j^{hk} = \gamma_j^{hkd} + \gamma_j^{hkf}$. Then,

$$\begin{aligned}\sum_{m=1}^{K} \gamma_j^{mk} n_j^m C_j^m + \gamma_j^{hk} E_j &= \sum_{m=1}^{K} \gamma_j^{mkd} n_j^m C_j^m + \gamma_j^{hkd} E_j + EX_j^k \\ &\quad + \sum_{m=1}^{K} \gamma_j^{mkf} n_j^m C_j^m + \gamma_j^{hkf} E_j - EX_j^k. \\ &= GO_j^k + IM_j^k - EX_j^k \,. \end{aligned} \tag{19}$$

The last equality follows from the fact that $\sum_{m=1}^{K} \gamma_j^{mkd} n_j^m C_j^m + \gamma_j^{hkd} E_j + EX_j^k$, which is equal to the home sales of domestically produced industry k goods plus their exports, must be equal to gross output GO_j^k, and $\sum_{m=1}^{K} \gamma_j^{mkf} n_j^m C_j^m + \gamma_j^{hkf} E_j = IM_j^k$.

Using (15) and (18), we rewrite (17) as

$$X_{ij}^k = n_i^k \left(\frac{\sigma^k}{1-\sigma^k}\, c_i^k\right)^{1-\sigma^k} \left(\frac{\tau_{ij}^k}{P_j^k}\right)^{1-\sigma^k} GO_j^k\,(1+\varphi_j^k), \tag{20}$$

where $\varphi_j^k \equiv (IM_j^k - EX_j^k)/GO_j^k$. The summation of X_{ij}^k over all j's, including domestic sales X_{ii}^k, must be equal to the gross output of industry k goods in country i.

$$GO_i^k = n_i^k \left(\frac{\sigma^k}{1-\sigma^k}\, c_i^k\right)^{1-\sigma^k} \left[\sum_j \left(\left(\frac{\tau_{ij}^k}{P_j^k}\right)^{1-\sigma^k} \frac{GO_j^k\,(1+\varphi_j^k)}{GO_W^k}\right)\right] GO_W^k. \tag{21}$$

$GO_W^k = \sum_j G_j{}^k$. Define

$$\Pi_i^k = \left[\sum_j \left(\left(\frac{\tau_{ij}^k}{P_j^k}\right)^{1-\sigma^k} \frac{GO_j^k\ (1+\varphi_j^k)}{GO_W^k}\right)\right]^{\frac{1}{1-\sigma^k}}. \tag{22}$$

Solving for $n_i^k \left(\frac{\sigma^k}{1-\sigma^k}\ c_i^k\right)^{1-\sigma^k}$ in (21), and plugging the solution into (20) together with (22) yields the gravity equation for a world with intermediate goods trade.

$$X_{ij}^k = \left(\frac{\tau_{ij}^k}{\Pi_i^k P_j^k}\right)^{1-\sigma^k} \frac{GO_i^k\ GO_j^k\ (1+\varphi_j^k)}{GO_W^k}. \tag{23}$$

Using (3), (15), and (21), we can show that

$$P_j^k = \left[\sum_i \left(\left(\frac{\tau_{ij}^k}{\Pi_i^k}\right)^{1-\sigma^k} \frac{GO_i^k}{GO_W^k}\right)\right]^{\frac{1}{1-\sigma^k}} \tag{24}$$

Equation (23) states that exports from country *i* to country *j* should be proportional to the product of two countries' masses, and diminish with bilateral trade costs between them. As Anderson and van Wincoop (2003) emphasize, bilateral trade costs should be measured relative to 'multilateral resistance' captured by Π_i^k and P_j^k. Equation (23) is essentially identical to the gravity equation derived by Anderson and van Wincoop (2003). The only difference is that here we are dealing with sectoral level trade covering both final goods and intermediate goods, and we use gross output to measure the mass of a country, not GDP.[2]

Equation (23) implies that using value-added as the mass variable is permissible to the extent that value-added is proportional to gross output. However, the ratio of value added to gross output given in (7) ($\frac{W_i\, L_i^m}{C_i^m}$), will change whenever the

[2] Another minor difference is that we adjust for trade imbalance.

intermediate good price index changes relative to the wage rate, unless the elasticity of substitution between labor and intermediate goods is equal to 1. With a non-unitary elasticity of substitution, the ratio will fluctuate whenever raw material prices, trade barriers or the number of intermediate goods change.

The equation that we will estimate comes from the logarithmic version of (23).

$$\ln X_{ij}^{k} = -\ln GO_{W}^{k} + \ln GO_{i}^{k}\, GO_{j}^{k} + \ln\ (1+\varphi_{j}^{k}) - (\sigma^{k}-1)\ln \tau_{ij}^{k} + (\sigma^{k}-1)\ln \Pi_{i}^{k} + (\sigma^{k}-1)\ln P_{j}^{k} + \varepsilon_{ij}. \qquad (25)$$

Time subscripts are dropped for notational simplicity. As is standard in the literature, we assume that bilateral transportation costs are determined by the following equation.

$$\left(\sigma^{k}-1\right)\ln \tau_{ij}^{k} = \alpha_0 + \alpha_1 \ln Distance_{ij} + \alpha_2\, Contiguity_{ij} + \alpha_3\, Common\_language_{ij} + \alpha_4\, Colony_{ij} + \alpha_5\, Common\_currency_{ij} + \alpha_6 RTA_{ij}. \qquad (26)$$

Contiguity, *Common language*, *Colony*, *Common currency*, and *RTA*, respectively, are dummy variables that take the value of one when country pair *i* and *j* share a border, share a common language, has been in colonial relationship, share a common currency, and belong to a regional trade agreement. We will capture the world output $\ln GO_{W}^{k}$ by year fixed effects. As has now become standard, the effects of multilateral resistance variables $(\sigma^{k}-1)\ln \Pi_{i}^{k}$ and $\left(\sigma^{k}-1\right)\ln P_{j}^{k}$, respectively, are estimated by exporter fixed effects and importer fixed effects.[3] Thus, our benchmark estimation equation is given by:

[3] Because multilateral resistance can change over time, we should, in principle, allow country fixed effects to vary over years. However, this necessitates plugging more than 1,000 dummy variables in the equation, and causes a collinearity problem with the mass variable $\ln GO_{i}^{k}\, GO_{j}^{k}$ and other dummies. Thus we allow for only time-invariant exporter and importer fixed effects

$$\ln X_{ij}^k = \beta_0 + \beta_1 \ln GO_i^k\, GO_j^k + \beta_2 \ln Net\_imports_j + \beta_3 \ln Distance_{ij} + \beta_4 Contiguity_{ij} + \beta_5 Common\_language_{ij} + \beta_6 Colony_{ij} + \beta_7\, Common\_currency_{ij} + \beta_8\, RTA_{ij} + Yea\_FE + Exporter\_FE + Importer\_FE + \varepsilon_{ij}. \quad (27)$$

$Net\_imports_j$ is equal to $1 + \varphi_j^k = 1 + (IM_j^k - EX_j^k)/GO_j^k$. FE refers to fixed effects.

III. SOME EMPIRICAL RESULTS

In this section, we test whether using gross output as the mass variable improves the empirical performance of the gravity equation. Our data come from the following sources. For bilateral trade, gross output, and value added, we use annual data from the World Input-Output Database Release 2013 (Timmer et al., 2015). The database provides annual data for 40 countries and 1560 (=40×39) country pairs, which include most major industrial countries and some emerging economies. Some data in the database are estimated rather than observed, but the database has the big advantage of providing the three interconnected variables in a mutually consistent way. Data for distance and the dummy variables come from the CEPII gravity dataset (Head, Mayer, and Ries, 2010; Head and Mayer, 2014). We will restrict our analysis to trade in manufacturing (industry 3 through industry 16). We take this choice because the manufacture sector took center stage in the rise of global value chains, and in the resulting increase in the ratio of gross output to value added during the last two decades. The period of examination is 13 years from 1995 through 2007. Note that this is the period when world trade as a share of GDP increased at a record speed with the rapid expansion of global value chains.[4]

[4] The database covers the period from 1995 through 2011. However, China's gross output to value added ratio, which is a key variable for our investigation, is fixed to a constant number during the period between 2008 and 2011, casting doubt on the quality of data during this period. We also want to avoid the period of trade turmoil after the Great Financial Crisis of 2008. However, our main results do not depend on dropping the period.

Estimation results using pooled OLS estimation are reported in Table 1. The main concern of Baldwin and Taglioni (2011) is that in the presence of intermediates trade, the conventional method of employing value added as the mass variable has the danger of generating bias in estimating the output elasticity of trade. They show that this bias reduces the estimated coefficient of the mass variable toward zero, more so for trade flows between country pairs doing massive intermediates trade. To check if this problem also shows up in our dataset, in regression (1), we use value added as the mass variable as in standard gravity equations. The coefficient of $\ln VA_i VA_j$ is estimated to be 0.89. For comparison, regression (2) employs the theoretically correct gross output as the mass variable. The R^2 minusculy increases and the estimates for trade costs variables are virtually unchanged, but the coefficient of the mass variable increases to 0.96. The hypothesis that it is equal to unity cannot be rejected at significance level less than 10 percent. Regression (3) is a formal test of our argument that in the presence of intermediate goods trade, the use of value added would generate bias in the estimation of the mass variable coefficient because of fluctuations in the ratio of gross output to value added. Because $\ln GO_i GO_j = \ln VA_i VA_j + \ln\ (GO_i GO_j)\ /\ (VA_i VA_j)$, we put both $\ln VA_i VA_j$ and $\ln\ (GO_i GO_j)/\ (VA_i VA_j)$ as regressors, and check if the estimated coefficient of $\ln VA_i VA_j$ increases toward one and the estimated coefficient of $\ln\ (GO_i GO_j)/\ (VA_i VA_j)$ is significant and close to one. . Indeed, we find that the estimated coefficient of $\ln VA_i VA_j$ increases to 0.96 and the estimated coefficient of $\ln\ (GO_i GO_j)/\ (VA_i VA_j)$ is equal to 1.01. Again, the hypothesis that these estimates are equal to unity cannot be rejected at significance level less than 10 percent.

In Table 2, we report estimation results when exporter and importer fixed effects are replaced by exporter-importer pair fixed effects. This exercise is for the possibility that explanatory variables that we placed to control for bilateral trade costs still omit some important variables affecting bilateral trade costs, and generate significant bias. In addition, for many policy questions, the response of trade over time is more relevant than that across countries. In Table 2, we can see that the coefficients of the mass variables change surprisingly little with country pair fixed effects, even though the coefficients for *Common Currency* and *RTA* undergo big changes.

Table 1. Value Added Vs. Gross Output in the Gravity Equation

$\ln X_{ij}$	(1)	(2)	(3)
$\ln VA_i VA_j$	0.89*** (0.04)		0.96*** (0.03)
$\ln GO_i GO_j$		0.96*** (0.03)	
$\ln\ (GO_i GO_j)/\ (VA_i VA_j)$			1.01*** (0.12)
$\ln Net\ Imports_j$	0.89*** (0.14)	0.22* (0.13)	0.19 (0.13)
ln *Distance*	-1.32*** (0.06)	-1.32*** (0.06)	-1.32*** (0.06)
Contiguity	0.39*** (0.13)	0.39*** (0.13)	0.39*** (0.13)
Common language	0.22* (0.12)	0.22* (0.12)	0.22* (0.12)
Colony	0.20 (0.16)	0.20 (0.16)	0.20 (0.16)
Common Currency	-0.20*** (0.06)	-0.20*** (0.06)	-0.20*** (0.06)
RTA	0.05 (.07)	0.05 (.07)	0.05 (.07)
Fixed Effects	year exporter importer	year exporter importer	year exporter importer
R^2	0.89	0.89	0.89
Obs.	20,274	20,274	20,274

Note: The intercepts are not reported. The numbers in the parentheses are robust standard errors clustered by country-pairs.

Table 2. Value Added Vs. Gross Output in the Gravity Equation: Panel Estimation

$\ln X_{ij}$	(4)	(5)	(6)
$\ln VA_i VA_j$	0.89*** (0.04)		0.96*** (0.04)
$\ln GO_i GO_j$		0.96*** (0.03)	
$\ln\ (GO_i GO_j)/\ (VA_i VA_j)$			1.01*** (0.12)
$\ln Net\ Imports_j$	0.87*** (0.13)	0.20 (0.13)	0.16 (0.14)

Table 2. Continued

$\ln X_{ij}$	(4)	(5)	(6)
Common Currency	-0.08*** (0.03)	-0.07** (0.03)	-0.07** (0.03)
RTA	0.18*** (.04)	0.19*** (.04)	0.19*** (.04)
Fixed Effects	year exporter-importer	year exporter-importer	year exporter-importer
R^2	0.44	0.45	0.45
Obs.	20,274	20,274	20,274

Note: Some bilateral costs variables in Tables 1 and 2 are dropped because they are constant over time. The intercepts are not reported. The numbers in the parentheses are robust standard errors clustered by country-pairs. R^2s are from within regressions.

As we emphasized before, our gravity equation holds both for aggregate trade and for industry level trade. Relying on this feature, we estimated gravity equations for 14 manufacturing industries. Regression results vary a lot from industry to industry. However, in almost all industries, using valued added alone as the mass variable results in the underestimation of its coefficient, and using gross output instead significantly raises the estimated coefficient. In addition, in all industries, the estimated coefficient of $\ln\ (GO_iGO_j)/\ (VA_iVA_j)$ is large and significant at 1 percent when it is included together with $\ln VA_iVA_j$.

Table 3 reports results for three selected industries. To save space, the results when $\ln GO_iGO_j$ alone is used as the mass variable are not reported. Cokes and refined petroleum industry represents the case where the coefficient of the mass variable is the most underestimated when value added alone is included as the mass variable. The estimated coefficient of $\ln VA_iVA_j$ is equal to 0.20, but it increases to 0.77 when $\ln\ (GO_iGO_j)/\ (VA_iVA_j)$ also is included. The huge increase probably stems from the fact that oil price changes caused big swings of gross output to value added ratio in the oil-using industry. Basic and fabricated metals industry represents a median case. The coefficient of $\ln VA_iVA_j$ modestly increases from 0.81 to 1.00 when $\ln\ (GO_iGO_j)/\ (VA_iVA_j)$ is included. Though not reported, similar results hold for most other industries. General machinery industry is selected as the case where the coefficient of the mass variable is the least underestimated with value added used as the mass variable. It increases from 0.84 to 0.87 with the inclusion of $\ln\ (GO_iGO_j)/\ (VA_iVA_j)$. This small increase is not observed in the other industries. We also ran regressions for individual manufacturing industries controlling for exporter-importer pair fixed effects. Though we do not report here, the coefficients of the mass variables change little.

Table 3. Value Added Vs. Gross Output in the Gravity Equation in Selected Industries

	Cokes and Refined Petroleum		Basic and Fabricated Metals		General Machinery	
$\ln X_{ij}$	(7)	(8)	(9)	(10)	(11)	(12)
$\ln VA_iVA_j$	0.20*** (0.03)	0.77*** (0.06)	0.81*** (0.05)	1.00*** (0.05)	0.84*** (0.05)	0.87*** (0.05)
$\ln\ (GO_iGO_j)/\ (VA_iVA_j)$		0.88*** (0.06)		1.19*** (0.12)		0.73*** (0.11)
$\ln Net\ Imports_j$	0.19* (0.11)	-0.12 (0.13)	0.69*** (0.12)	0.04 (0.13)	0.66*** (0.10)	0.08 (0.12)
ln *Distance*	-2.38*** (0.10)	-2.36*** (0.10)	-1.68*** (0.08)	-1.68*** (0.08)	-1.37*** (0.07)	-1.37*** (0.07)
Contiguity	0.65*** (0.23)	0.66*** (0.23)	0.31* (0.17)	0.31* (0.17)	0.26 (0.18)	0.25 (0.18)
Common language	-0.04 (0.21)	-0.05 (0.21)	0.37** (0.17)	0.37** (0.17)	0.18 (0.15)	0.17 (0.15)
Colony	0.56** (0.22)	0.58** (0.22)	0.29 (0.21)	0.29 (0.21)	0.47** (0.21)	0.47** (0.21)
Common Currency	-0.52*** (0.14)	-0.50*** (0.14)	-0.41*** (0.08)	-0.41*** (0.08)	-0.61*** (0.08)	-0.58*** (0.08)
RTA	-0.20 (0.14)	-0.12 (0.14)	0.09 (0.10)	0.09 (0.10)	-0.07 (0.09)	-0.05 (0.09)
Fixed Effects	year exporter importer	year exporter importer	year exporter importer	year exporter importer	year exporter importer	year exporter importer
R^2	0.74	0.74	0.84	0.84	0.85	0.85
Obs.	20,274	20,274	20,274	20,274	20,274	20,274

Note: The intercepts are not reported. The numbers in the parentheses are robust standard errors clustered by country-pairs.

The question that we are pursuing here is whether we should use value added or gross output to correctly estimate the elasticity of trade with respect to output. The literature on the gravity equation, however, has moved away from the issue. The gravity equation is mainly used as a tool for evaluating the effect on trade volume of shocks reducing trade barriers, such as free trade agreements, currency unions, or lower transportation costs. Therefore, researchers' interests converged on correctly estimating the elasticities of trade with respect to trade frictions. These elasticities can be consistently estimated in the gravity equation without specifying the mass variable. Instead of using $\ln VA_i VA_j$ as a single regressor, we could place $\ln VA_i$ and $\ln VA_j$ as separate regressors, and let them be subsumed by exporter and importer fixed effects. One research area where this strategy is not workable is to decompose observed trade volume changes into component parts: the contribution of output changes, the contribution of transportation costs changes, and the contribution of trade policy changes. Notable examples in this line of research are Baier and Bergstrand (2001), Estevadeordal, Frantz, and Taylor (2003), and Novy (2013). Here we have to correctly specify the mass variable and correctly estimate its coefficient not to underestimate the role of output and hence overestimate the role of trade frictions in trade volume changes.[5]

To get a sense on how important the correct specification of the mass variable is in decomposing trade expansion, we construct Table 4. Column (1) shows the growth of Korea's manufactured exports to the world and its top 10 importers between 1995 and 2007. Columns (2) and (3), respectively, display the ratio of percentage increase in value added to percentage increase in exports, and the ratio of percentage increase in gross output to percentage increase in exports. Column (4) shows the ratio of percentage increase in importer's net imports to percentage increase in exports. The numbers in the third row, which accounts for Korea's exports to the world, are obtained by calculating the weighted averages of the numbers corresponding to individual countries, each weight given by the average share of an importer in Korea's total exports during the period.[6] The row shows that Korea's manufactured exports grew 113% during the period, and 75% of the

[5] Correctly estimating the output elasticity of trade is also important in understanding the recent slowdown of world trade relative to GDP growth. See Constantinescu, Mattoo and Ruta (2015).

[6] The World Input-Output Database provides Korea's exports to 39 other countries and the rest of the world. The rest of the world accounts for 26 percent of Korea's total exports.

growth can be attributed to the growth of valued added produced by Korea and its trading partners. The number increases to 84% when gross output is used instead of value added as the output variable. This is because the ratio of gross output to value added increased in Korea and other countries. Column (4) shows that the part explained by importer's net imports is small at -1.4%. The following rows report results for individual countries. They vary a lot from country to country. However, we can notice that for all countries, the part explained by gross output is larger than that by valued added. The part explained by importer's net imports is large in some countries.

Table 4. Decomposing Korea's Manufacturing Export Growth Between 1995 and 2007

(Unit: percent)

Importer	$\Delta \ln X_{ij}$	$\frac{\Delta \ln (VA_i VA_j / \ln VA_W)}{\Delta \ln X_{ij}}$	$\frac{\Delta \ln (GO_i GO_j / \ln GO_W)}{\Delta \ln X_{ij}}$	$\frac{\Delta \ln Net\ Imports_j}{\Delta \ln X_{ij}}$	0.89 ×(2)
	(1)	(2)	(3)	(4)	(5)
World	112.9	74.9	83.5	-1.4	66.7
USA	50.7	118.6	137.1	10.6	105.6
China	191.3	91.8	103.0	-3.1	81.7
Japan	28.0	-25.4	20.3	-12.9	-22.6
Taiwan	103.4	47.6	58.3	-17.0	42.4
Germany	79.4	66.0	72.8	-20.0	58.8
RUS	217.3	68.2	72.7	0.9	60.7
CAN	68.0	116.4	144.0	10.6	103.6
MEX	241.0	53.3	54.4	2.3	47.4
GBR	70.8	77.9	99.0	15.1	69.3
AUS	109.8	71.9	87.9	5.2	64.0

Column (5) was obtained by multiplying 0.89, the estimated coefficient of $\ln VA_i VA_j$ in Tables 1 and 2, to column (2). Thus, the gravity equation using value added as the mass variable would have attributed 67% of Korea's export growth to increases in the output scales of Korea and its partners, implying that the contribution of lower trade costs can be as large as 33%. The number increases to 84% when we use gross output as the mass variable, reducing the room for the contribution of trade costs to 16%. This increase is due to the increase in gross output to value added ratio, and the increase in the estimated coefficient of the mass variable. The increase is not large, but substantial.

IV. CONCLUSION

In this paper, we propose a simple solution to the problem of estimating the gravity equation in the presence of intermediate goods trade. All we have to do is to use gross output in place of value added as the mass variable. This method can reduce bias coming from fluctuations in gross output to value added ratio, which would naturally arise in the world where intermediate goods are heavily traded through global supply networks.

Through some empirical exercises, we show that bias is not quite large, but significant for the gravity equation in manufacturing trade. However, huge bias can arise for an industry level gravity equation, as we demonstrate in the case of petroleum refining industry. We also show that this bias can result in exaggerating the role of reduced trade barriers in explaining the recent expansion of world trade. In the case of Korea's export growth between 1995 and 2007, the possible contribution of reduced trade barriers shrinks from 33% to 16% of Korea's total export growth. This suggests that the effect of trade policy changes like the Korea-US FTA or the Korea-EU FTA could be substantially overestimated with the conventional gravity equation using GDP as the mass variable.

One limitation of our study is that our empirics focused only on the period in which world trade rapidly expanded with the rise of global value chains. It will be an interesting exercise to test whether our findings are still valid for the period after 2011, in which world trade shrank relative to GDP. However, the new release of the World Input-Output Database contains only a few observations on the period, and observations for the recent years in which world trade shrank most, are not feasible yet. Thus, we leave it to our future investigations.

Finally, we would like to mention that the approach of this paper can trace only one face of global value chains through the ratio of gross output to value added. Thus, it has a serious limitation as a portrait of changing global production networks. Its usefulness should be found as a simple way of supplementing other methods of investigating world trade structure.

REFERENCES

Aichele, R. and I. Heiland. 2014. "Where is the Value Added? China's WTO Entry, Trade and Value Chains," In Beiträge zur Jahrestagung des Vereins für Socialpolitik 2014: Evidenzbasierte irtschaftspolitik-Session: China's Growing Role in World Trade, no. E12-V3.

Anderson, J. E., Milot, C. A. and Y. V. Yotov. 2014. "How Much Does Geography Deflect Services Trade? Canadian Answers," *International Economic Review*, vol. 55, no. 3, pp. 791-818.

Anderson, J. E. and E. van Wincoop. 2003. "Gravity with Gravitas: A Solution to the Border Puzzle," *American Economic Review*, vol. 93, no. 1, pp. 170-192.

Baier, S. L. and J. H. Bergstrand. 2001. "The Growth of World Trade: Tariffs, Transportation Costs, and Income Similarity," *Journal of International Economics*, vol. 53, no. 1, pp. 1-27.

Baldwin, R. E., Skudelny, F. and D. Taglioni. 2005. "Trade Effects of the Euro: Evidence from Sectoral Data," ECB Working Paper, no. 446.

Baldwin, R. and D. Taglioni. 2011. "Gravity Chains: Estimating Bilateral Trade Flows When Parts and Components Trade is Important," NBER Working Paper, no. 16672.

Bridgman, B. 2012. "The Rise of Vertical Specialization Trade," *Journal of International Economics*, vol. 86, no. 1, pp. 133-140.

Constantinescu, C., Mattoo, A. and M. Ruta. 2015. "The Global Trade Slowdown: Cyclical or Structural?," IMF Working Paper, no. 15/6.

Chaney, T. 2008. "Distorted Gravity: The Intensive and Extensive Margins of International Trade," *American Economic Review*, vol. 98, no. 4, pp. 1707-1721.

Eaton, J. and S. Kortum. 2002. "Technology, Geography, and Trade," *Econometrica*, vol. 70, no. 5, pp. 1741-1779.

Estevadeordal, A., Frantz, B. and A. M. Taylor. 2003. "The Rise and Fall of World Trade, 1870-1939," *Quarterly Journal of Economics*, vol. 118, no. 2, pp. 359-407.

Evans, C. L. 2003. "The Economic Significance of National Border Effects," *American Economic Review*, vol. 93, no. 4, pp. 1291-1312.

Feenstra, R. C., Markusen, J. A. and A. K. Rose. 2001. "Using the Gravity Equation to Differentiate among the Alternative Theories of Trade," *Canadian Journal of Economics*, vol. 34, no. 2, pp. 430-447.

Head, K., Mayer, T. and J. Ries. 2010. "The Erosion of Colonial Trade Linkages after Independence," *Journal of International Economics*, vol. 81, no. 1, pp. 1-14.

Head, K. and T. Mayer. 2014. Gravity Equations: Workhorse, Toolkit, and Cookbook. In Gopinath, G., Helpman E. and K. Rogoff. (eds.) *Handbook of International Economics*, vol. 4. Amsterdam: Elsevier.

Hummels, D., Ishii, J. and K.-M. Yi. 2001. "The Nature and Growth of Vertical Specialization in World Trade," *Journal of International Economics*, vol. 54, no. 1, pp. 75-96.

Jang, S. 2014. "Vertical Specialization and Gravity Equation Estimation," Master Thesis, Sogang University.

Johnson, R. C. and G. Noguera. 2012. "Accounting for Intermediates: Production Sharing and Trade in Value Added," *Journal of International Economics*, vol. 86, no. 2, pp. 224-236.
Koopman, R., Wang, Z. and S-J. Wei. 2014. "Tracing Value-Added and Double Counting in Gross Exports," *American Economic Review*, vol. 104, no. 2, pp. 459-494.
Krugman, P. R. 1979. "Increasing Returns, Monopolistic Competition, and International Trade," *Journal of International Economics*, vol. 9, no. 4, pp. 469-479.
Krugman, P. and A. J. Venables. 1996. "Integration, Specialization, and Adjustment," *European Economic Review*, vol. 40, no. 3-5, pp. 959-967.
Novy, D. 2013. "Gravity Redux: Measuring International Trade Costs with Panel Data," *Economic Inquiry*, vol. 51, no. 1, pp. 101-121.
Rauch, J. E. 1999. "Networks versus Markets in International Trade," *Journal of International Economics*, vol. 48, no. 1, pp. 7-37.
Saito, M. 2004. "Armington Elasticities in Intermediate Inputs Trade: A Problem in Using Multilateral Trade Data," *Canadian Journal of Economics*, vol. 37, no. 4, pp. 1097-1117.
Timmer, M. P., Dietzenbacher, E., Los, B., Stehrer, R. and G. J. de Vries. 2015. "An Illustrated User Guide to the World Input–Output Database: The Case of Global Automotive Production," *Review of International Economics*, vol. 23, no. 3, pp. 575-605.
Wei, S.-J. 1996. "Intra-National versus International Trade: How Stubborn are Nations in Global Integration?," NBER Working Paper, no. 5531.
Yi, K.-M. 2003. "Can Vertical Specialization Explain the Growth of World Trade?," *Journal of Political Economy*, vol. 111, no. 1, pp. 52-102.

First version received on 17 October 2017
Peer-reviewed version received on 4 November 2017
Final version accepted on 29 November 2017