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Conference Paper

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51st Congress of the European Regional Science Association: "New Challenges for European Regions and Urban Areas in a Globalised World", 30 August - 3 September 2011, Barcelona, Spain

Provided in Cooperation with:

European Regional Science Association (ERSA)

Suggested Citation: Spies, Julia; Kleinert, Joern (2011) : Transport Costs in International Trade, 51st Congress of the European Regional Science Association: "New Challenges for European Regions and Urban Areas in a Globalised World", 30 August - 3 September 2011, Barcelona, Spain, European Regional Science Association (ERSA), Louvain-la-Neuve

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Transport Costs in International Trade*

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March 1, 2011

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Abstract

This paper claims that distance alone is a poor proxy for international transport costs in gravity equations. We develop a theoretical framework with a manufacturing and a transport sector, where the level of manufacturing exports determines the demand for transport. Above a certain threshold, transport service suppliers find it profit-maximizing to invest into advanced transport technology, which lowers their marginal costs and as a consequence, transport prices. Transport costs therefore vary with the distance between the two locations, and with the endogenous decision to invest in a more efficient technology. We tackle the biases in traditional gravity estimates by using newly collected data on transport prices from UPS and by applying instrument variable estimation techniques. Our results reveal that distance affects trade beyond the transport cost channel. Transport prices, in turn, are influenced by the distance and by the exports between two countries. We find that trading partners with 10% more exports enjoy 0.7% lower transport prices.

Keywords: Gravity equation, distance, endogenous transport costs
JEL: F12, F15, R41

*This project has benefited from the joint support of the French and German science foundations ANR and the DFG. Special thanks go to Maria Fenger Jensen and Lena Tonzer, who provided most valuable research assistance.

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1 Introduction

Globalization has provoked a substantial fall in trade costs. These cost reductions seem to be asymmetrically distributed across countries, though. While most Asian economies, first and foremost, China, trade high volumes at moderate transport prices with the EU, many African economies do the reverse and trade rather moderate volumes at high transport prices – despite of their more favorable geographic location. This observation questions the traditional handling of transport costs as constant and exogenously given iceberg-costs and suggests instead that trade and transport costs are mutually interdependent.

Endogeneity problems in gravity equations have provoked lengthy discussions in the trade literature of the past decade. Nearly all of the typically employed variables have been surmised to simultaneously influence trade, and be influenced by trade. The usual suspects include national incomes (Frankel and Romer, 1999) and Free Trade Agreements (FTAs) (see e.g. Baier and Bergstrand, 2004 and Egger et al., 2010). A notable exception are transport costs. Mostly approximated by time-invariant distance, transport costs have even served as an instrument variable for trade assuming their orthogonality to other gravity variables (Frankel and Romer, 1999). Hummels (2007), however, suggests that distance plays only a moderate role among transport costs determinants. Instead, he speculates that the amount of trade has “significant impacts on shipping prices through scale effects”. Rudolph (2010) argues that average transport costs decline with trade if fixed costs of production give rise to economies of scale. In this case, transport costs are subject to reverse causality considerations and introduce a bias into the parameters estimates just like other variables.

In this paper, we develop a theoretical framework in which the demand for transport in the manufacturing sector affects investment decisions and hence prices in the transport sector. Allowing for asymmetric countries in accordance with Melitz and Ottaviano (2008), we show that transport routes exhibiting large export volumes make investments into advanced transport technologies more likely and feature consequently, lower trans-

port prices than transport routes with small export volumes. Relying only on distance to approximate transport costs is not sufficient to account for these mechanisms. Using Monte-Carlo simulations, we show that traditional gravity estimates potentially suffer from two different biases: first, since the unobserved technology choice is correlated with the GDPs and distances of the trading countries, there is an omitted variable bias. Second, since the investment decision depends on the export level itself, there is also a reverse causality bias. Using newly collected data on UPS shipping prices between 61 countries, we confirm that distance alone is an insufficient predictor of transport costs in gravity equations. Our results based on instrumental variable techniques indicate that, in addition, transport prices are 0.7% lower on trade routes with a 10% higher bilateral export value.

The outline of the paper is as follows: after embedding the paper into the literature in Section 2, we develop the theoretical model in Section 3. We illustrate the bias in Section 4 using generic data. Section 5 reports the empirical results using real data. Section 6 concludes.

2 Related Literature

The determinants of trade cost variations across products and trade routes have recently gained interest. Hummels et al. (2009) propose a model of the transport sector to analyze the effect of market power in international shipping on prices in transport and therefore on trade. The theoretical frame of an oligopolistic market with symmetric suppliers guides their empirical specification of prices and mark-ups. Using two micro-level data sets, Hummels et al. (2009) assess the effect of the number of suppliers, the demand elasticity of a particular good, the price-weight ratio, and the tariff rate of a country. Trade cost variations across different products and routes can be attributed to differences in market power whose impact on shipping prices exceed the impact of distance. These findings explain why developing countries, which are often confronted with an inelastic shipping demand and relatively high tariffs, also show higher costs of transport.

Starting with Clark et al. (2004), a number of empirical studies have identified economies of scale as a determinant of transport costs (see e.g. Wilmsmeier et al., 2006, Martínez-Zarzoso and Wilmsmeier, 2010 and Pomfret and Sourdin, 2010). Using the gap between c.i.f and f.o.b values of Australian imports as a measure of transport costs, Pomfret and Sourdin (2010) show that country size explains some of the variation in trade costs along with distance, the weight of the product, and the institutional quality of the exporting and/or the importing country. Once imports are used as a regressor instead of GDP to approximate country size, the significantly negative effect on trade costs becomes larger and more robust.

Only a few of the studies identifying scale effects address and correct, however, the bias resulting from the two-way causality between trade and trade costs. Clark et al. (2004) use GDP as an instrumental variable assuming that any effect of country size on transport costs goes via trade volumes. The finding of higher trade costs on routes with lower trade volumes gets more pronounced when exports are instrumented, suggesting that failing to account for the endogeneity of exports understates their impact. Rudolph (2009) argues that scale economies leading to falling average costs arise in the presence of fixed costs in the trade sector. Not accounting for the endogenous impact of trade on transport costs biases the coefficients traditionally employed in gravity equations. Rudolph (2010) applies a simultaneous equation model to jointly estimate trade and trade costs, the latter being approximated by the trade volume within the respective trading partner economies relative to the trade volume between them. His findings are twofold: First, there is simultaneity in the form of a negative effect of trade on trade costs. Second, ignoring the simultaneity results in overestimating the impact of trade cost proxies on trade. Hence, properly accounting for the reverse causality allows to provide a more reliable estimate of the effect of transport costs on trade and adds, thereby, to the solution of the distance puzzle.

3 Theoretical Framework

This section develops a two sector model of manufacturing M and transport T . In the monopolistically competitive manufacturing sector, heterogenous firms select into markets featuring asymmetric sizes and per-unit transport costs, hence giving rise to differing export quantities. In the oligopolistic transport sector, symmetric suppliers offer a homogenous transport service to ship the manufacturing goods into the export markets.

3.1 The Manufacturing Sector

For the manufacturing sector, we adopt a Melitz and Ottaviano (2008)-framework with an economy consisting of L consumers and N firms facing per-unit transport costs when engaging in export activities.

Consumers

Following Melitz and Ottaviano (2008), country j 's consumption of manufacturing goods from country i is subject to a quadratic utility function,

$$U_j = q_{ij}^c(0) + \alpha \int_{m \in \Omega_j} q_{ij}^c(m) dm - \frac{1}{2} \gamma \int_{m \in \Omega_j} (q_{ij}^c(m))^2 dm - \frac{1}{2} \eta \left(\int_{m \in \Omega_j} q_{ij}^c(m) dm \right)^2, \quad (1)$$

where $q_{ij}^c(0)$ and $q_{ij}^c(m)$ refer to the individual consumption of the numeraire and the differentiated good. Whereas α and η indicate the degree of substitutability between the differentiated varieties and the numeraire, γ indicates the degree of differentiation between the varieties. To simplify the notation, we drop m hereafter. The inverse demand is given by

$$p_{ij} = \alpha - \gamma q_{ij}^c - \eta Q_{ij}^c. \quad (2)$$

With $q_{ij} = L_j q_{ij}^c$ and $q_{ij}^c > 0$, we obtain the subset of varieties which satisfies

$$p_{ij} \leq \frac{1}{\eta N_j + \gamma} (\gamma \alpha + \eta N_j \bar{p}_j). \quad (3)$$

Prices p_{ij} are inclusive of per-unit transport costs, $p_{ij} = p_i + t_{ij}$.

Producers

Firms maximize profits

$$\pi = q_{ij} (p_{ij} - c_k - t_{ij}) \quad (4)$$

and obtain their optimal output as

$$q_{ij} = \frac{L_j}{\gamma} (p_{ij} - c_k - t_{ij}). \quad (5)$$

For the marginal firm, which is indifferent about exiting, prices are driven down to marginal costs, $p_{ij} = c_k + t_{ij}$. We denote the maximum marginal costs for firms from country i to remain in market j as \hat{c}_{ij} . Equating the threshold and the optimal output gives the equilibrium price and quantity,

$$p_{ij} = \frac{1}{2} (\hat{c}_{ij} + c_k + t_{ij}) \quad (6a)$$

$$q_{ij} = \frac{L_j}{2\gamma} (\hat{c}_{ij} - c_k - t_{ij}). \quad (6b)$$

We aggregate over all q_{ij} , which are produced with marginal costs $c_k + t_{ij} \leq \hat{c}_{ij}$,

$$Q_{ij} = N_{ij} \frac{L_j}{2\gamma} \int_0^{\hat{c}_{ij}} (\hat{c}_{ij} - c_k - t_{ij}) dG(c_k). \quad (7)$$

We assume that the productivities of the firms from country i , which have sufficiently low marginal costs to enter market j follow a Pareto distribution $G(c_k) = \left(\frac{c_k}{\hat{c}_{ij}}\right)^\delta$ with support $[0; \hat{c}_{ij}]$. With this, we can express Q_{ij} as a function of the maximum costs to stay in the market,

$$Q_{ij} = N_{ij} \frac{L_j}{2\gamma} \left(\frac{1}{\delta + 1} \hat{c}_{ij} - t_{ij} \right). \quad (8)$$

Since the number of country i -firms active in country j equals the share of exporters, $N_{ij} = \left(\frac{G(\hat{c}_{ij})}{G(\hat{c}_i)}\right) N_i$, we can express the total quantity of exported manufacturing goods

as

$$Q_{ij} = \left(\frac{\hat{c}_i}{\hat{c}_i - t_{ij}} \right)^\delta \frac{N_i L_j}{2\gamma} \left(\frac{1}{\delta + 1} (\hat{c}_i - t_{ij}) - t_{ij} \right). \quad (9)$$

Similarly, we obtain total bilateral export values by aggregating each firm's export sales $r_{ij} = p_{ij}q_{ij}$ over all exporter's from i to j ,

$$\begin{aligned} EX_{ij} &= N_{ij} \frac{L_j}{4\gamma} \int_0^{\hat{c}_{ij}} (\hat{c}_{ij}^2 - c_k^2 - t_{ij}^2 - 2t_{ij}c_k) dG(c_k) \\ &= N_{ij} \frac{L_j}{4\gamma} \left[\hat{c}_{ij}^2 \left(1 - \frac{\delta}{\delta + 2} - \frac{\delta}{\delta + 1} \frac{2t_{ij}}{\hat{c}_{ij}} \right) - t_{ij}^2 \right] \\ &= \left(\frac{\hat{c}_i}{\hat{c}_i - t_{ij}} \right)^\delta \frac{N_i L_j}{4\gamma} \left[(\hat{c}_i - t_{ij})^2 \left(1 - \frac{\delta}{\delta + 2} - \frac{\delta}{\delta + 1} \frac{2t_{ij}}{\hat{c}_i - t_{ij}} \right) - t_{ij}^2 \right]. \end{aligned} \quad (10)$$

Equation (10) shows that the aggregate bilateral export values are characterized by a gravity-type relation where the country sizes N_i and L_j exhibit a positive and transport costs t_{ij} a negative impact on exports.¹

3.2 The Transport Sector

As the transport sector typically consists of a few, large companies, we impose an oligopolistic market structure. We assume that transport is a homogenous service. Consequently, exporting firms will base their decision for a particular transport service supplier entirely on cost considerations. To keep the model simple and to focus on differences in the aggregate pattern of transport costs between two countries, we will model the transport sector as consisting of symmetric firms.² In a world with i exporting and j importing countries, $i \times j$ transport routes exist. We assume that each transport firm serves each route. The total number of transport firms n^T is exogenously given.³

Transport firms choose their transport technology when starting to service a par-

¹See Appendix A.1 for a proof that the partial derivative $\frac{\partial Q_{ij}}{\partial t_{ij}} < 0$. Since t_{ij} is homogenous and therefore independent of p_{ij} , it follows that $\frac{\partial EX_{ij}}{\partial t_{ij}} < 0$, too.

²In reality, it is likely that the transport service sector consists of heterogenous suppliers. Imposing symmetry does, however, not affect our main argument while simplifying the analysis considerably.

³The number of firms could be endogenized by allowing for a fixed cost of market entry in the transport sector f_T . Deriving the number of transport firms endogenously would not alter our results, which focus on the differences between routes.

ticular route. Similar to Yeaple (2005) and Bustos (2011), we simplify the investment problem by assuming that there are just two possible cost structures to choose from: one (technology H) with low variable costs and high fixed costs, and one (technology L) with high variable but low fixed costs, i.e. $a^H < a^L$ and $f^H > f^L$. We assume that the investment is specific to a particular route, i.e. to the service between countries i and j . Consequently, marginal costs of shipping one unit of a manufactured good between i and j , a_{ij}^l differ with the chosen technology and between any two routes.⁴ The total cost function of transport firms is then described as

$$A_{ij}(t) = a_{ij}q_{ij}(t) + f \quad (11)$$

and the profit function as

$$\pi_{ij}(t) = t_{ij}q_{ij}(t) - A_{ij}(t), \quad (12)$$

where t_{ij} is the homogenous price for the transport service.⁵ The total demand for transport services, as derived from manufacturing exports, equals the total amount shipped by each transport firm, $Q_{ij}(t) = \sum_{h=1}^{n^T} q_{ij}(t)$. From (12), we obtain the profit-maximizing quantity,

$$q_{ij} = \left(\frac{t_{ij} - a_{ij}}{t_{ij}} \right) \varepsilon Q_{ij}, \quad (13)$$

with $\varepsilon = -\frac{\partial Q_{ij}}{\partial t_{ij}} \frac{t_{ij}}{Q_{ij}}$ as the price elasticity of demand. Output, i.e. the supply of transport services, increases in the transport price t_{ij} and the export quantity Q_{ij} . With the demand strictly falling and the supply strictly rising in the transport price t_{ij} , there exists exactly one transport price level that clears the market for transport services. Note further, that the output of a transport service supplier is negatively affected by the cost a_{ij} of supplying the service.

Aggregating over all firms' outputs in the transport sector yields the transport price

⁴Since all variables except n^T depend on the chosen technology, we drop l hereafter.

⁵While t_{ij} represents transport costs for the manufacturing sector, it represents transport prices for the transport sector. We use both terms alternatively, depending on whether we refer to the manufacturing or the transport sector.

t_{ij} as a function of the firms' costs, the number of firms n^T and the demand elasticity ε ,

$$t_{ij} = \frac{\sum_{h=1}^{n^T} a_{ij}}{n^T - \frac{1}{\varepsilon}}. \quad (14)$$

We use the optimal output derived in (13) to rewrite the profits (12) in a way that makes the cost structure more explicit,

$$\pi_{ij}(t) = (t_{ij} - a_{ij})q_{ij} - f = \frac{(t_{ij} - a_{ij})^2}{t_{ij}}\varepsilon Q_{ij} - f. \quad (15)$$

With this outline, we can now study the incentive to invest in a cost saving transport technology for the route between countries i and j . Equation (16) uses (14) together with the symmetry assumption regarding transport firms' costs to show that profits in the transport sector increase as the marginal costs of shipping fall,

$$\begin{aligned} \frac{d\pi_{ij}}{da_{ij}} &= \frac{\partial \mu_{ij}}{\partial a_{ij}}\varepsilon Q_{ij} + \frac{\partial Q_{ij}}{\partial a_{ij}}\varepsilon \mu_{ij} \\ &= B \frac{n^T}{\varepsilon(n^T - 1/\varepsilon)} Q_{ij} < 0, \end{aligned} \quad (16)$$

where $B = 1 - \left(\frac{(1+\delta)[2\hat{c}_i - (2+\delta)t_{ij}]}{(\hat{c}_i - t_{ij})[\hat{c}_i - (2+\delta)t_{ij}]} \right) \frac{n^T a_{ij}}{n^T - \frac{1}{\varepsilon}} < 0$ if the marginal costs a_{ij} in the transport sector are not too low.⁶ In the following, we assume that the marginal costs of shipping are sufficiently high to ensure the negative relationship. Note that there is a trade-off between lower mark-ups and larger demand following the cost reduction. Since the second effect outweighs the first, profits increase with falling costs. Equation (16) shows furthermore that the profit-rising effect of investing into advanced technologies increases with the output Q_{ij} of the manufacturing sector that is exported from country i to country j .

The comparison of profits guides the firm's decision of investing in one of the two available technologies. The transport supplier will decide to invest into the advanced technology if the lower marginal costs generate sufficiently high variable profits to make

⁶See Appendix A.2 for a proof that profits are decreasing in marginal costs.

up for the higher fixed costs. The discussion above reveals that this is more likely for transport routes with high trading volumes, i.e. if Q_{ij} is high,

$$d\pi_{ij} = B \frac{n^T}{\varepsilon(n^T - 1/\varepsilon)} Q_{ij} da_{ij} > f^H - f^L, \quad (17)$$

where $da_{ij} = a_{ij}^H - a_{ij}^L < 0$. Hence, since the technology choice depends on the trade volume we expect lower transport prices on routes featuring large trade volumes. The chosen technology affects the marginal costs and therefore the transport prices,

$$t_{ij}^l = \begin{cases} \frac{n^T a_{ij}^H}{n^T - 1/\varepsilon^H} & \text{for a high trading volume} \\ \frac{n^T a_{ij}^L}{n^T - 1/\varepsilon^L} & \text{for a low trading volume.} \end{cases} \quad (18)$$

4 Estimating Trade: An Illustrative Example

The main insight from the theoretical model is that approximating transport costs by distance and other distance-related variables is not sufficient in the presence of a transport sector with optimizing transport service suppliers. Hummels et al. (2009) point out that omitting the part of equation (18) that is related to market power, $\frac{n\varepsilon}{(n-1)}$, affects the estimation of gravity trade equations. We complement this finding by adding the role of technology choice which impacts transport prices via the marginal costs a_{ij} of supplying transport services between two locations i and j . These costs vary with the distance between the two locations, other geographical and cultural distance-related variables, and with the decision to invest in a more efficient technology for transport services between the two locations.

While the distance-related variables are exogenous, the investment decision is not. It depends on the trade value or volume. As transport costs fall following the implementation of the more efficient technology, trade levels rise. However, a transport service supplier will only implement the more efficient technology if trade levels are high enough. As a consequence, high trade levels induce low transport costs which induce, in turn, high trade levels. This circular effect shows that traditional gravity estimates of bilateral trade

suffer from an endogeneity bias resulting in too high coefficients of the income and distance variables. Using distance to approximate transport costs omits the relative price effect that comes along with higher trade levels. Instead, this relative price effect is added to the demand effect approximated by GDP.

A simple simulation exercise helps to illustrate the bias. We generically create a data set of 1000 trading partners of a country. These 1000 countries have an arbitrary size ($GDP_j > 0$) drawn from a uniform distribution with mean 500. Their distance ($dist_{ij}$) from the "home country" is drawn from a uniform distribution with mean 150. We stick to the simplest set-up with only one "home country", which spares us constructing a consistent matrix of distances between any two country pairs while still illustrating the endogeneity argument. Additionally, we draw two error terms from a uniform distribution with mean one. The descriptive statistics are given in Table A.1 in the Appendix. All results are obtained from repeating the simulation 10000 times.

We use equations (10) and (18) to compute trade levels and transport costs from the constructed data set. Equation (10) suggests that the export level which goes from country i to country j is a positive function of the market size of country j , GDP_j , and a negative function of the transport costs, t_{ij} .⁷ u_{ex} is the error term.

$$exports_{ij} = 0.05(GDP_j)/t_{ij} * u_{ex} \quad (19)$$

As indicated by equation (18), transport prices, t_{ij} , are, in turn, a function of the transport firm's market power $\eta = \frac{n^T}{n^T - 1/\epsilon}$ and of its marginal costs. The marginal costs are increasing in the distance, $dist_{ij}$, between the two countries and decreasing in an indicator variable, I_{ij} , which describes the firm's technology choice. $I_{ij} = 2$ if the transport firm faces $exports_{ij} > 15$ and invests in the route between the two countries and $I_{ij} = 1$ otherwise.⁸ In line with the empirical literature, the distance exponent is < 1 reflecting

⁷Without loss of validity, the simulation does not reflect all non-linearities from the theoretical model. In order to allow for zero trade flows arising from the cost threshold \hat{c}_i , we could introduce a reporting limit. Since we test the model with aggregate trade data on OECD countries, zero export flows are not important.

⁸The high transport cost group consists on average of 777.42 countries.

that transport costs are concave in distance. Thus, we have

$$t_{ij} = \eta * 0.2(dist_{ij})^{0.6}/I_{ij} * u_t \quad \text{with } I_{ij} = 1, 2. \quad (20)$$

Having ruled out the possibility of heteroskedasticity in the error terms and of zero trade flows, we can log-linearize equation (19) and obtain a standard gravity equation augmented by the technology choice indicator,

$$\ln(exports_{ij}) = \alpha + \beta_1 \ln(GDP_j) + \beta_2 \ln(dist_{ij}) + \beta_3 \ln(I_{ij}) + \ln(u_{ex}) \quad (21)$$

where η is absorbed by the constant term α .⁹ The technology choice indicator, I_{ij} , is usually unobserved (along with the transport costs, t_{ij}) and therefore omitted when estimating equation (21).

The endogeneity bias stems from two sources. The first problem relates to the correlation between the omitted variable, I_{ij} , and the explanatory variables, GDP_j (correlation coefficient: 0.36) and $dist_{ij}$ (correlation coefficient: -0.36). Hence, these explanatory variables are not orthogonal to the error term in traditional gravity estimations. A proxy variable that is strongly correlated with the omitted variable but does not have a direct effect on exports could alleviate the bias. In our case, with the discrete investment as a marginal cost shifter, a dummy variable indicating the top 50, top 100 or top 200 export markets works well.

Since the coefficient of the investment indicator is positive, the sign of the covariance between the omitted variable and the regressors, GDP_j and $dist_{ij}$, determines the direction of the bias. $\beta_3[Cov(GDP_j, I_{ij})/Var(GDP_j)]$ gives the magnitude of the bias of β_1 and $\beta_3[Cov(distance_{ij}, I_{ij})/Var(distance_{ij})]$ gives the magnitude of the bias of β_2 (Wooldridge, 2002). Thus, the positive covariance of the indicator with the GDP and the negative covariance with distance indicates the upward bias of β_1 and the downward bias of β_2 when omitting the investment indicator as done in traditional gravity estimation.

⁹Under the assumption of global competition in the transport sector, it is plausible to treat η as a constant. To account for the possibility of bilateral competition, we also report estimation results with country dummies.

Table 1: Addressing the omitted variable bias in gravity equations

	True model	Omitting I_{ij}	Approximating by Top 50	Approximating by Top 100	Approximating by Top 200
Dependent variable: $exports_{ij}$					
GDP	0.846 (0.022)	1.088 (0.030)	1.041 (0.028)	0.984 (0.027)	0.872 (0.023)
Distance	-0.392 (0.023)	-0.719 (0.030)	-0.571 (0.032)	-0.492 (0.029)	-0.406 (0.024)
Indicator	2.738 (0.082)				
Proxy			1.515 (0.146)	1.695 (0.099)	1.863 (0.062)

Note: Standard errors in parentheses.

Source: Own calculations.

The second problem causing the endogeneity bias relates to the proposition that the investment indicator is not merely a function of partner country's GDP and the bilateral distance. Instead, it reflects an endogenous decision of transport service suppliers, which affects the level of their marginal costs. Therefore, as much as the export level depends on transport costs, the decision whether to invest depends on the bilateral export level. In equilibrium, both variables are jointly determined. A single equation framework as in equation (22) is therefore not appropriate to tackle the endogeneity of the export level.

$$\ln(exports_{ij}) = -3.063 + 0.996 \ln(GDP_j) - 1.049 \ln(t_{ij}) \quad (22)$$

Rewriting equation (20) as $t_{ij} = 0.2(dist_{ij})^{0.6}/I_{ij}(exports_{ij})$ gives together with equation (19) rise to a system of simultaneous equations,

$$\ln(t_{ij}) = \alpha_t + \beta_{t,1} \ln(dist_{ij}) - \beta_{t,2} \ln(exports_{ij}) + u_t \quad (23a)$$

$$\ln(exports_{ij}) = \alpha_{ex} + \beta_{ex,1} \ln(GDP_j) + \beta_{ex,2} \ln(t_{ij}) + u_{ex}, \quad (23b)$$

in which the GDP of the partner country and the bilateral distance identify the two equations. Comparing the coefficients of the single equation and the system equation

estimation, the bias appears to be small,

$$\ln(t_{ij}) = -2.039 + 0.661 \ln(dist_{ij}) - 0.081 \ln(exports_{ij}) \quad (24a)$$

$$\ln(exports_{ij}) = -3.134 + 1.000 \ln(GDP_j) - 1.000 \ln(t_{ij}). \quad (24b)$$

The numerical example confirms the insight from the theoretical model that it is not sufficient to approximate transport costs with distance. Instead, we need to consider and address two sources of bias: first, there is an omitted variable bias resulting from the unobservable technology choice and second, there is a bias stemming from the reverse causality of trade and transport prices.

5 Estimating Trade: An Empirical Test

After illustrating the biases introduced by using only distance to approximate transport costs with a generic data set, we employ real data on UPS transport prices to test these findings empirically.

5.1 Data

Bilateral transport costs are difficult to measure.¹⁰ We build a new data set by collecting information from UPS on the costs of shipping a 10kg package per express delivery between two countries. 2010 transport prices are available for 61 countries. In cases where different prices apply to different regions of one country, we take the prices of the region the most populated city belongs to.

We analyze the transport prices charged on different routes together with bilateral trade data. The OECD ICTS database provides bilateral trade data for 30 OECD countries with partner countries worldwide. The latest available year is currently 2009. We select the 61 trade partners for which we were also able to gather information on transport

¹⁰ Attempts to derive transport costs from c.i.f. versus f.o.b. prices are subject to inconsistencies due to discrepancies in trade reporting. A limited number of countries (the US, New Zealand, Argentina, Brazil, Chile, Paraguay and Uruguay) report freight expenditures in import customs declarations.

prices. In total, we have a data set containing $30 * 61 - 30 = 1800$ observations.

GDPs in current US\$ are obtained from the World Development Indicators (WDI). Geodesic distances between the most populated cities of two countries are calculated using the great circle formula. We suspect that distance exercises an impact on trade which goes beyond its impact on transport costs. If this is the case, distance might not serve as a valid instrument for transport prices. In order to control for informal relations that boost trade but are unrelated to transport costs, we include dummy variables for sharing a common language, being in a colonial relationship, belonging to the same empire, and a variable reflecting differences in time zone. All distance and distance-related variables are provided by CEPII. Information on Regional Trade Agreements (RTAs) is updated using the World Trade Organization's RTA database.

5.2 Results

We start with estimating the transport price and the export equation separately. In order to make our results comparable to a wide range of empirical studies relying on the gravity equation, we primarily report OLS estimates. In accordance to the findings of Silva and Tenreyro (2006), we additionally provide Poisson PML results, since the former are found to be consistent in the presence of heteroskedasticity even if zero trade flows are not problematic as in our case.

Table 2 shows the estimation of transport prices as a function of distance and distance-related variables. The OLS estimates in column (1) indicate that firms set higher prices on more distant routes, involving countries which are not in a colonial relationship or have enforced a trade agreement. The impact of distance on transport prices is surprisingly low. Transporting goods between countries which are 10% farther away from each other is only 2.34% more expensive, on average. These results remain generally robust when applying Poisson PML estimation in column (2), and when additionally considering the impact of the bilateral export value on transport prices, as in columns (3) and (4). In line with our theoretical hypothesis, transport service suppliers charge 0.69% (0.63% in the Poisson PML estimation) lower transport prices on routes with 10% higher export

Table 2: Estimation of Transport Prices

	OLS	Poisson	OLS	Poisson
Dependent variable: t_{ij}				
Distance	0.234*** (0.024)	0.235*** (0.023)	0.159*** (0.022)	0.163*** (0.022)
Border	-0.058 (0.102)	-0.019 (0.113)	0.041 (0.078)	0.061 (0.088)
Time difference	-0.072** (0.034)	-0.092*** (0.029)	-0.051** (0.024)	-0.066*** (0.021)
Colony	-0.147** (0.058)	-0.138** (0.061)	-0.073 (0.057)	-0.085 (0.056)
Empire	-0.052 (0.059)	-0.035 (0.047)	0.032 (0.048)	0.043 (0.038)
RTA	-0.090*** (0.022)	-0.090*** (0.021)	-0.086*** (0.016)	-0.080*** (0.015)
Exports			-0.069*** (0.007)	-0.063*** (0.006)
N	1,413	1,413	1,413	1,413
R^2	0.70	0.64	0.77	0.70

Note: Cluster-robust standard errors in parentheses with significance at the *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ level. All regressions contain exporter dummies.

Source: Own calculations.

levels. At the same time, all other coefficients drop with the inclusion of bilateral exports, indicating that their omission causes an upward bias in the explanatory variables. While bilateral distance remains the strongest predictor of transport prices, there is no one-to-one relation as suggested by the gravity literature which often relies on distance to approximate transport costs.

Table 3 contains the estimation results of the gravity equation, again applying OLS and Poisson PML estimation. All coefficients have the expected sign throughout the different specifications. In columns (1) and (2), we report results from the traditional specification of the gravity equation. In line with Silva and Tenreyro (2006), we find that the distance coefficient drops in the Poisson PML estimation. Preferential trade arrangements even lose their significant impact on trade flows entirely. In columns (3) and (4), we include transport prices instead of distance and find them to have an even stronger impact on exports. This is in line with Hummels et al. (2009) who emphasize that transport prices reflect market power in addition to the marginal costs in the transport

Table 3: Estimation of Trade Flows

	OLS	Poisson	OLS	Poisson	OLS	Poisson
Dependent variable: $exports_{ij}$						
GDP_j	0.948*** (0.028)	0.836*** (0.026)	0.867*** (0.02)	0.760*** (0.028)	0.875*** (0.022)	0.769*** (0.026)
GDP_i	1.087*** (0.017)	0.946*** (0.019)	0.924*** (0.013)	1.327*** (0.024)	1.005*** (0.025)	1.415*** (0.033)
Distance	-0.655*** (0.085)	-0.399*** (0.058)			-0.470*** (0.097)	-0.280*** (0.071)
Border	0.538** (0.232)	0.647*** (0.177)	1.022*** (0.325)	0.724*** (0.253)	0.593** (0.242)	0.609*** (0.231)
Time difference	-0.197* (0.099)	-0.344*** (0.054)	-0.465*** (0.067)	-0.368*** (0.063)	-0.212** (0.091)	-0.311*** (0.062)
Colony	0.668*** (0.181)	0.16 (0.219)	0.515** (0.19)	0.09 (0.226)	0.508** (0.188)	0.069 (0.212)
Empire	0.813*** (0.179)	0.162 (0.142)	0.797*** (0.145)	0.345* (0.185)	0.786*** (0.132)	0.246* (0.138)
Language	0.443*** (0.121)	0.257** (0.111)	0.298** (0.127)	0.087 (0.179)	0.410*** (0.11)	0.221* (0.126)
RTA	0.469*** (0.139)	0.167 (0.178)	0.433*** (0.117)	0.199 (0.145)	0.348*** (0.112)	0.07 (0.154)
Transport prices			-1.259*** (0.163)	-1.126*** (0.158)	-0.876*** (0.183)	-0.704*** (0.207)
N	1,447	1,447	1,384	1,384	1,384	1,384
R^2	0.849	0.92	0.857	0.917	0.864	0.923

Note: Cluster-robust standard errors in parentheses with significance at the *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ level. All regressions contain exporter dummies.

Source: Own calculations.

sector. When including distance along with transport prices in columns (5) and (6), both, the distance and the transport price effect decrease, as expected. Nevertheless, both variables keep exercising a significant and economically important impact on exports, suggesting that transport costs are only one channel through which distance affects trade.

The single equation estimations confirm the mutual dependence of trade and transport costs. Consequently, both variables need to be instrumented.¹¹ Valid instruments for exports and transport prices must fulfill two criteria: first, they need to be independent from the residuals of the transport price and export equation, respectively, and second, they need to be sufficiently correlated with the included endogenous regressors.

In the transport price equation, both countries' GDPs along with the language dummy serve as instruments for bilateral exports. In the gravity equation, we use a dummy variable indicating the top 5 export markets, similar to Section 4. Even though the single equation estimations indicate that distance influences trade also via channels other than transport costs, it might serve as an instrument for transport prices as long as it is orthogonal to the error term of the gravity equation. Columns (1) and (2) of Table 4 contain the results of the IV estimation along with tests of the validity of the employed instruments. Hansen's J test of overidentifying restrictions confirms that the chosen set of instruments is uncorrelated with the respective error terms. The Kleibergen-Paap statistic further reports a sufficient correlation of the instruments with the endogenous regressors. Hence, by fulfilling both criteria, we can be confident that our instruments are indeed valid.

Turning to the results from the IV estimation of the gravity equation, column (1) reports a very high transport price coefficient of -3.3. While having a common border and belonging to the same empire keep their sign, magnitude and significance levels, a common language, being in a colonial relationship or having an RTA no longer significantly affect bilateral exports. Column (2) contains the results from estimating the transport price equation with instrumental variables. The presumption of low transport

¹¹The C-tests reported at the bottom of columns (1) and (2) of Table 4 strongly reject the null hypotheses that transport prices and exports are exogenous and thereby reinforce the need for IV estimation.

Table 4: System Estimation of Trade Flows and Transport Prices

Dependent variable	IV-GMM	IV-GMM	System	
	$exports_{ij}$	t_{ij}	$exports_{ij}$	t_{ij}
GDP_j	0.707*** (0.03)		0.705*** (0.028)	
GDP_i	1.069*** (0.073)		0.734*** (0.081)	
Distance		0.152*** (0.014)		0.149*** (0.012)
Proxy		-0.082*** (0.025)		-0.097*** (0.019)
Border	0.553* (0.298)	0.07 (0.066)	0.579** (0.263)	0.079 (0.055)
Time difference	-0.301*** (0.054)	-0.057*** (0.013)	-0.302*** (0.051)	-0.054*** (0.012)
Colony	0.307 (0.191)	-0.066* (0.036)	0.211 (0.173)	-0.063* (0.033)
Empire	0.842*** (0.174)	0.048 (0.029)	0.741*** (0.145)	0.048* (0.026)
Language	0.241 (0.147)		0.368*** (0.095)	
RTA	0.036 (0.109)	-0.097*** (0.02)	0.033 (0.102)	-0.098*** (0.018)
Transport prices	-3.300*** (0.285)		-3.292*** (0.277)	
Exports		-0.070*** (0.004)		-0.069*** (0.004)
N	1,384	1,384	1,384	1,384
R^2	0.816	0.775	0.816	0.775
C-test	73.841	8.195	-	-
p-value	0.000	0.004	-	-
Hansen J test	0.723	0.906	-	-
p-value	0.395	0.342	-	-
Kleibergen-Paap test	124.36	1108.098	-	-
R^2 excluded IVs	0.175	0.682	-	-

Note: Standard errors in parentheses with significance at the *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ level. All regressions contain exporter dummies. The IV-GMM estimates are robust to heteroskedasticity.

Source: Own calculations.

prices on routes with high levels of exports is confirmed. Distance keeps being one of various transport price determinants. Instrumenting exports, the influence of distance on transport prices has, however, dropped to a coefficient of 0.15. These findings strengthen our reasoning that it is not sufficient to rely only on distance to approximate bilateral transport cost.

In addition to the IV-GMM results, we provide results from the estimation of a system of equations, as specified in equation (24), in columns (3) and (4) of Table 4. The coefficients are very similar.

6 Conclusions

Unlike most of the literature that assumes exogenously set, iceberg-type transport costs, this paper proposes marginal costs and prices in the transport sector to be endogenous to bilateral export levels between two countries. Setting up a theoretical framework which comprises a manufacture and a transport sector, we show that optimizing transport service suppliers invest in modern transport technology on highly frequented trade routes. The technology choice impacts transport prices via the marginal costs of supplying transport services between two locations. Under these conditions, it is not sufficient to approximate transport costs by distance and distance-related variables like done the vast majority of empirical applications of the gravity equation.

Using a constructed data set, we illustrate that the bias stemming from the omission of the investment decision in the transport sector, and its endogeneity to bilateral trade levels can be cured using instrumental variable techniques. Employing a new data set which contains information on UPS transport prices, we detect an influence from exports on transport prices, and vice versa.

Even though the paper's contribution is mainly methodological, some important policy implications emerge as well: With a circular effect of bilateral trade causing lower bilateral transport prices, which, in turn, stimulate bilateral trade, it is not surprising that late-comer countries from the developing world find it ever more difficult to increase

their exports.

A Appendix

A.1 Derivation of the Negative Slope of the Demand Function

Demand is given by (9) which can be written as

$$Q_{ij} = \hat{c}_i^\delta \frac{N_i L_j}{2\gamma} (\hat{c}_i - t_{ij})^{-\delta} \left(\frac{1}{1+\delta} \hat{c}_i - \frac{\delta+2}{\delta+1} t_{ij} \right) \quad (\text{A.1})$$

The partial derivative with respect to transport costs t_{ij} reads

$$\begin{aligned} \frac{\partial Q_{ij}}{\partial t_{ij}} &= -\delta (\hat{c}_i - t_{ij})^{-1} \hat{c}_i^\delta \frac{N_i L_j}{2\gamma} (\hat{c}_i - t_{ij})^{-\delta} \left(\frac{\hat{c}_i - (2+\delta)t_{ij}}{1+\delta} \right) \\ &\quad - \frac{\delta+2}{\delta+1} \hat{c}_i^\delta \frac{N_i L_j}{2\gamma} (\hat{c}_i - t_{ij})^{-\delta} \\ &= - \left(\frac{\delta}{\hat{c}_i - t_{ij}} + \frac{2+\delta}{\hat{c}_i - (2+\delta)t_{ij}} \right) Q_{ij} < 0 \end{aligned}$$

Since $\hat{c}_i - (2+\delta)t_{ij}$ is non-negative, the partial derivative is negative.

A.2 Derivation of the Negative Slope of the Profit Function

The change of profits in reaction to a cost reduction has two components: (i) the mark-up $\frac{(t_{ij}-a_{ij})^2}{t_{ij}}$ decreases and (ii) the demand Q_{ij} increases. Thus, $d\pi_{ij} = \frac{\partial \mu_{ij}}{\partial a_{ij}} da_{ij} \varepsilon Q_{ij} + \frac{\partial Q_{ij}}{\partial a_{ij}} da_{ij} \varepsilon \mu_{ij}$. We derive the two effects in turn. We write the mark-up μ as $\mu = \left(\frac{\frac{1}{\varepsilon} a_{ij}}{n^T - \frac{1}{\varepsilon}} \right)^2 \left(\frac{n^T a_{ij}}{n^T - \frac{1}{\varepsilon}} \right)^{-1} = \frac{n^T a_{ij}}{\varepsilon^2 (n^T - \frac{1}{\varepsilon})}$.

$$\frac{d\mu(a)}{da_{ij}} = \frac{n^T}{\varepsilon(n^T - 1/\varepsilon)} Q_{ij} \quad (\text{A.2})$$

The second part involves the partial derivation of demand with respect to costs of supplying transport $\frac{\partial Q_{ij}}{\partial a_{ij}} = \frac{\partial Q_{ij}}{\partial t_{ij}} \frac{\partial t_{ij}}{\partial a_{ij}} = - \left(\frac{\delta}{\hat{c}_i - t_{ij}} + \frac{2+\delta}{\hat{c}_i - (2+\delta)t_{ij}} \right) Q_{ij} \frac{n^T}{n^T - \frac{1}{\varepsilon}} \cdot \frac{dQ_{ij}}{da_{ij}}$ yields

$$\begin{aligned} \frac{dQ_{ij}}{da_{ij}} &= - \left(\frac{\delta}{\hat{c}_i - t_{ij}} + \frac{2+\delta}{\hat{c}_i - (2+\delta)t_{ij}} \right) Q_{ij} \frac{n^T}{n^T - \frac{1}{\varepsilon}} \frac{n^T a_{ij}}{\varepsilon(n^T - 1/\varepsilon)} \\ &= - \frac{n^T}{\varepsilon(n^T - 1/\varepsilon)} Q_{ij} \underbrace{\left(\frac{(1+\delta)[2\hat{c}_i - (2+\delta)t_{ij}]}{(\hat{c}_i - t_{ij})[\hat{c}_i - (2+\delta)t_{ij}]} \right)}_{>1 \text{ iff } a_{ij} \text{ is not too low}} \frac{n^T a_{ij}}{n^T - \frac{1}{\varepsilon}} \end{aligned}$$

The effect of *decreasing* marginal costs a_{ij} on profits in the transport sector is therefore positive, if marginal costs in the transport sector are not too low.

$$\frac{d\pi_{ij}}{da_{ij}} = \left[1 - \underbrace{\left(\frac{(1+\delta)[2\hat{c}_i - (2+\delta)t_{ij}]}{(\hat{c}_i - t_{ij})[\hat{c}_i - (2+\delta)t_{ij}]} \right)}_B \frac{n^T a_{ij}}{n^T - \frac{1}{\varepsilon}} \right] \frac{n^T}{\varepsilon(n^T - 1/\varepsilon)} Q_{ij} < 0 \quad (\text{A.3})$$

$$\frac{\partial q_{ij}}{\partial t_{ij}} = \frac{c_{ij}}{t_{ij}^2} \epsilon Q_{ij}$$

A.3 Descriptive Statistics of the Generic Data

Table A.1: Descriptive Statistics

Variable	Mean	Std.Dev.	Min	Max
Distance	149.94	86.59	0.302	299.70
GDP	499.95	288.68	0.993	999.01
u_t	1	0.492	0.283	1.997
u_{ex}	1	0.492	0.283	1.997

Source: Own calculations.

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