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# Endogenous transport costs and international trade

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## Abstract

In this paper, we model a manufacturing and a transport sector and use export volumes to determine the demand for transport services. If trade exceeds a particular level, transport service suppliers maximise profit by investing in an advanced transport technology, which lowers their marginal costs and reduces equilibrium transport prices. Transport costs thus vary according to *two* characteristics: the distance between two locations and the endogenous firm decision to invest in transportation. A simulation exercise reveals that ignoring the effect of the investment decision on transport costs biases empirical results. We apply this insight in our empirical estimations which rely on repeatedly collected transport price data from the United Parcel Service. We use an instrumental variable estimator to account for the endogeneity of the investment decision. Our estimation results confirm that transport prices are influenced by both the distance and the level of exports between two countries. We find that trading partners with 10% more exports enjoy on average 0.6% lower transport prices.

## KEYWORDS

distance, endogenous transport costs, OLS/Poisson estimation

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## 1 | INTRODUCTION

The declining cost of cross-border transactions has accelerated the international trade of goods and services over the two decades preceding the financial crisis, the ‘era of globalisation’. At the same time, increased cross-border transactions have boosted investments in international trade infrastructure, further reducing transportation costs. However, most of the empirical studies ignore the interdependence of infrastructure investment, lower transport costs and higher trade volumes.

We start with the observation that the cost of transporting goods between two countries varies not only in relation to distance. While many Asian countries like China, for instance, trade high volumes at moderate transport prices with the United States and the European Union, most African economies trade with them rather moderate volumes at high transport prices—despite their more favourable geographic location. According to data from the United Parcel Service (UPS) and for the case of Germany (see [Table 1](#)), the same 10 kg package send by UPS is 30% more expensive for German exporter if send to Nigeria than to China, although the distance to Nigeria is only 75% of the distance to China. If we compare Poland and the USA as destination countries, it is 15% more expensive to ship a package to Germany’s neighbour country Poland than across the Atlantic to the USA. Moreover, it is more than twice as expensive for German exporters to send a package to Algeria than to Iceland although the distance is almost the same.

Distance is not the only factor affecting transport costs. The recent literature has stressed that transport costs differ systematically with the market structure of the transport sector Hummels et al. (2009), bilateral trade imbalances (Behrens & Picard, 2011; Jonkeren et al., 2011; Brancaccio et al., 2017), port efficiencies (Blonigen & Wilson, 2008; Clark et al., 2004), and infrastructure investment in the exporting and importing countries (Donaubauer et al., 2018). Complementing these findings, we argue first that trade volumes affect the choice of transport technology by the logistics sector and second that bilateral trade levels are a significant, yet largely neglected, driver of differences in route-specific transport prices. Defining ‘investment’ in a wide manner, it includes the choice of transport mode and is not necessarily based on firm decisions. Public

**TABLE 1** UPS prices for sending a 10 kg package from Germany, 2019

Range	Destination	Distance (km)	Direction	Price
Short distance	Poland	520	East	305.50 €
	Netherlands	570	West	142.00 €
	Austria	520	South	142.00 €
	Denmark	350	North	142.00 €
Medium distance	Russia	1500	East	331.45 €
	Spain	1800	West	237.40 €
	Algeria	1930	South	728.90 €
	Iceland	2040	Northwest	331.45 €
Long distance	China	7360	East	435.80 €
	USA	6700	West	267.20 €
	India	5780	Southeast	435.80 €
	Nigeria	5200	South	615.40 €

*Note:* Distances are calculated as shortest distance between the capital cities.

*Source:* Dataset of transport prices by UPS (2020), geodesic distances by CEPII (2020). Own calculation.

investment in infrastructure or institutional improvement at the EU level, for instance, is likely to reduce logistics costs on a particular route. With respect to firms, the decision is made about the transport mode (i.e. van, truck, train and plain), the set-up of a logistics hub, a railway cargo centre or direct flight connections with air cargo planes. Many of these (firm) decisions involve higher fix cost but reduce variable costs of transportation.

We focus on such investment decisions of transport service suppliers and develop a theoretical framework that explicitly models a manufacturing and a transport sector. Transport service suppliers can choose between two route-specific technologies: (i) a 'high variable-/low fixed-costs' technology and (ii) a 'low-variable-/high fixed-costs' technology. This technology choice is motivated by increasing returns to scale in the transport sector.<sup>1</sup> Since a certain trade level is required to recover fixed costs, the technology choice of the transport sector depends on the trade level. As a consequence, the high (low) fixed-costs technology will be used on routes with high (low) bilateral trade levels. The interdependence explains the difference in transport prices, especially between trading locations within the same distance. If the price effect of an investment in a high fixed-costs technology is strong, technology investments might be as (or even more) important than distance in determining transport prices. The good news of this finding is that geography is not a destiny; the bad news is, however, that despite an advantageous location, there might be a vicious circle of low trade volumes resulting in low route-specific investments with high prices and low trade levels.

We assess the importance of the investment decision in the transport sector on route-specific transport prices by a theoretical framework, which is used to guide the empirical estimations. While we rely on a set of two equations and two endogenous variables (transport prices and trade levels), we focus on the estimation of the transport price equation, but take the endogeneity of trade levels into account. We analyse and estimate the transport price equation by a two-step approach. First, we use a generic data set to simulate our model in a controlled environment in order to determine the best strategy for dealing with the interdependence of transport prices and trade levels. Second, we apply this strategy to bilateral trade and transport price data from 30 exporting and 61 importing countries ( $30 \times 61 - 30 = 1800$  country pairs) for each of 4 years (2010, 2013, 2017 and 2019). The sample size is determined by the availability of transport prices from UPS and its country-specific rate and service guides (UPS, 2020).<sup>2</sup>

The estimates show that transport prices are indeed strongly affected by bilateral trade levels. Increasing the size of exports by 10%, for example reduces the transport price *ceteris paribus* by 0.6% on average. Given that trade levels differ strongly between trading routes, we consider the economic effect to be strong. According to the data, export values on the busiest route is 16 billion times higher compared with least busy route (Iceland-Ivory coast, 2017) and 74 times higher than the average in the sample. In a world where goods and services compete with close substitutes from several countries, we believe that this transport price advantage is likely to affect trade patterns.

The rest of the paper is as follows. In the next section, we relate our approach to the literature and develop the theoretical model in Section 3. We illustrate the estimation strategy in Section 4

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<sup>1</sup>Clark et al. (2004), for instance, report that transport and handling costs per container decrease significantly with the size of the ship and that '*maritime routes with low trade volumes are covered by small vessels and vice versa*'. (p. 423). A very illustrative example of economies of scale in shipping can also be found in The Economist (2011). See also Ganapati et al. (2020).

<sup>2</sup>UPS, FedEx or DHL offer transport services in a specific segment of trade. Bulky, heavy mass goods are not likely to be transported by these logistics firms. There is no 'favourite transport mode': car, truck, rail, plane or a combination of them are all used depending on the route. The prices are door-to-door prices. Our study is therefore complementary to those using container freights between ports.

using generic data and report the empirical results in Section 5 using empirical data. In Section 6, we discuss the results in a broader context. Section 7 presents conclusions.

## 2 | RELATED LITERATURE

Despite widespread interest in the globalisation process, there are surprisingly few studies that deal explicitly with transport costs. Hummels et al. (2009) propose an oligopolistic market with symmetric suppliers in the transport sector to analyse the effect of market power in international shipping on transport prices (and therefore on trade costs). Using two micro-level data sets, they 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 on transport prices. The study shows that transport price variations across different goods and routes are significantly explained by differences in market power on the trading routes, where the impact of market power on shipping prices exceeds the impact of distance.

Behrens and Picard (2011) study the effects of logistic problems of backhauling in a new economic geography framework. They explicitly model a transport sector which accounts for the profits lost by returning empty containers and show that the resulting transport price wedge increases with trade imbalances. In particular, firms in the net exporting country face higher transport costs, firms in the net importing country face lower transport costs, if transport firms optimise prices for the return journey.<sup>3</sup> This is supported by Brancaccio et al. (2017), who show by quantitative estimates that trade imbalances induce price differences (see also Wong (2020)). A number of empirical studies have identified economies of scale as a determinant of transport costs (see e.g. Clark et al., 2004; Ganapati et al., 2020; Martínez-Zarzoso & Wilmsmeier, 2010; Pomfret & Sourdin, 2010; Wilmsmeier et al., 2006). Clark et al. (2004) find higher transport costs on routes with lower trade volumes. Assuming that the effect of country size on transport costs runs through trade volumes, they use GDP as a proxy for trade volume and find a negative effect on transport prices, which becomes more pronounced when exports are instrumented. Using the gap between CIF and FOB values of Australian imports, Pomfret and Sourdin (2010) show that country size explains some of the variation in transport costs (in addition to the distance, the weight of the product and the institutional quality of the exporting and/or the importing country). When imports are used as a regressor instead of GDP, the significantly negative effect on transport costs becomes larger and more robust. Clark et al. (2004) and Blonigen and Wilson (2008) turn the focus to technology and argue that port efficiencies explain the country-specific part of transport cost variations, whereas variables such as distance, trade imbalances and product shares capture the bilateral transport cost determinants.<sup>4</sup> Donaubaueer et al. (2018) extends this argument to more infrastructure investment in the exporting and the importing country.

Closest to our approach is a study by Skiba (2007), who assumes a transport price function (with economies of scale) that increases in the distance between two countries and the good's price-weight ratio, and decreases in the export level. We differ from Skiba (2007) in that we model the transport price as endogenously determined in the transport sector. The decision to supply transport services includes the decision about an investment in a particular transport

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<sup>3</sup>This price wedge works against agglomeration forces. Thus, endogenous transport prices mitigate the separations of core and periphery countries, which is prominent in the models using iceberg transport costs.

<sup>4</sup>See also Rudolph (2009) and Rudolph (2010) and their focuses on economies of scale in the transport sector.

technology.<sup>5</sup> We work with a globally operating logistics sector which is characterised by imperfect competition. We thereby account for route-specific infrastructure investments which includes country-specific infrastructure investments.

### 3 | THEORETICAL FRAMEWORK

In this section, we develop a two-sector model to formalise the argument that bilateral trade levels and bilateral transport prices are jointly determined. The model comprises an oligopolistic transport sector,  $T$ , with a fixed number  $n^T$  of firms producing a homogeneous transport service for each route, and a manufacturing sector  $M$ , where exporting firms face per-unit transport costs. Prices are determined in equilibrium such that the quantities of transport services offered equal the quantities of goods shipped on behalf of the manufacturing sector. We model the manufacturing sector based on Melitz and Ottaviano (2008)'s model with a quasi-linear demand structure and additive transport costs. We choose a set-up in which labour is the only factor of production, where  $L_j$  is the number of people in economy  $j$ , each offering one unit of (homogeneous) labour.

#### 3.1 | The manufacturing sector

The manufacturing sector consists of  $N$  heterogeneous firms engaged in monopolistic competition. Firms set prices according to marginal costs, which depend on the firm-specific productivity level (drawn independently at market entry from a common distribution). This firm-specific productivity is the primary source of firm heterogeneity. The secondary source of heterogeneity is the firm's export status which results from differences in firms' productivity. In this static framework, we are interested in the fraction of income consumers spend on tradable manufactured goods.

##### 3.1.1 | Consumers

Following Melitz and Ottaviano (2008), preferences of a representative individual from country  $j$  are described by a quadratic utility function,

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

<sup>5</sup>Although we focus on the determinants of transport prices, our analysis relates also to the strand of literature that deals with the correct specification of the gravity equation. Endogeneity problems in gravity equations have provoked intense discussions in the trade literature in recent decades. Most of the included variables are believed to bilaterally interact with trade variables (i.e. national incomes (Frankel and Romer (1999))) and free trade agreements (FTAs) (see e.g. Baier and Bergstrand (2004) and Egger et al. (2010)). The notable exception is transport costs, which are usually 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). In line with Hummels (2007), we believe that the amount of trade has 'significant impacts on shipping prices through scale effects' and challenge thereby the orthogonality of transport costs.

where  $q_{ij}^c(0)$  and  $q_{ij}^c(m)$  refer to the individual consumption of the numeraire and the differentiated good,  $m$ . The first index  $i$  refers to the country where the production of the differentiated good,  $m$ , takes place. The second index,  $j$ , refers to the home country of the consumer.  $\alpha$  and  $\eta$  indicate the degree of substitutability between the differentiated varieties and the numeraire  $\gamma$  governs the degree of differentiation between the varieties. The inverse demand function is given by

$$p_{ij}(m) = \alpha - \gamma q_{ij}^c(m) - \eta Q_{ij}^c, \tag{2}$$

where  $Q_{ij}^c = \int_{m \in \Omega_j} q_{ij}^c(m) dm$ . With  $q_{ij} = L_j q_{ij}^c$  and  $q_{ij}^c > 0$ , we obtain the subset of produced varieties, which satisfies

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

and  $\bar{p}_j$  denotes the average price in country  $j$  with  $\bar{p}_j = 1/N \sum_m p_{ij}(m)$ . The consumer price of variety  $m$   $p_{ij}(m)$  includes per-unit transport costs,  $p_{ij}(m) = p_i(m) + t_{ij}$ , if the good is imported ( $j \neq i$ ).

### 3.1.2 | Producers

Assuming that product differentiation is free of charge, each good  $m$  is produced by only one firm. Firms maximise profits,

$$\pi_{ij}(m) = q_{ij}(m) [p_{ij}(m) - c_i(m) - t_{ij}] \tag{4}$$

in the foreign market ( $i \neq j$ ) and in the domestic market (i.e.,  $i = j$  and  $t_{ii} = 0$ ) independently. While products enter the consumption bundle symmetrically, we keep the firm index  $m$  because firms differ with respect to their productivity level. Firm-specific productivity levels translate into firm-specific marginal costs  $c_i(m)$ , firm-specific prices  $p_{ij}(m)$  and firm-specific output levels  $q_{ij}(m)$ . Using the residual demand from (2), firms obtain their output function as

$$q_{ij}(m) = \frac{L_j}{\gamma} [p_{ij}(m) - c_i(m) - t_{ij}] \tag{5}$$

Firm stay in the domestic market and enter a foreign market if their price equals at least the marginal costs,  $p_{ij}(m) = c_i(m) + t_{ij}$ , respectively. We denote the maximum marginal costs for firms from country  $i$  to be active in market  $j$  as  $\hat{c}_{ij}$ . These costs equal the price  $\hat{p}_{ij}$  set by the least productive exporter from country  $i$  in market  $j$ , which satisfies (3) with equality. Using this equality and the residual demand as given in (2) and (5), the equilibrium price and quantity of firm  $m$  can be expressed in terms of the marginal costs of firm  $m$  and the maximum marginal costs to survive in country  $j$ ,  $\hat{c}_j$ :

$$p_{ij}(m) = \frac{1}{2} (\hat{c}_{ij} + c_i(m)) + t_{ij} = \frac{1}{2} (\hat{c}_j + c_i(m) + t_{ij}) \tag{6a}$$

$$q_{ij}(m) = \frac{L_j}{2\gamma} (\hat{c}_{ij} - c_i(m)) = \frac{L_j}{2\gamma} (\hat{c}_j - c_i(m) - t_{ij}). \tag{6b}$$

We aggregate over all  $q_{ij}(m)$  which are produced with marginal costs  $c_i(m) + t_{ij} \leq \hat{c}_j$  to derive the total export volume  $Q_{ij}$  that firms from country  $i$  ship to country  $j$ :

$$\begin{aligned} Q_{ij} &= N_i \frac{L_j}{2\gamma} \int_0^{\hat{c}_j - t_{ij}} (\hat{c}_j - c_i(m) - t_{ij}) g(c_i(m)) dc_i(m) \\ &= N_i \underbrace{\left( \frac{\hat{c}_j - t_{ij}}{\hat{c}_i} \right)^\delta}_{N_{ij}} \frac{L_j}{2\gamma} \left[ \frac{1}{\delta+1} \hat{c}_j - \frac{\delta+2}{\delta+1} t_{ij} \right]. \end{aligned} \quad (7)$$

We assume that productivity of active firms from country  $i$  follow a Pareto distribution,  $G(c_i(m)) = \left( \frac{c_i(m)}{\hat{c}_i} \right)^\delta$ , with support  $[0; \hat{c}_i]$ , which we have applied in the second line of Equation (7). This allows us to express  $Q_{ij}$  as a function of the maximum costs in  $j$ ,  $\hat{c}_j$ , of  $t_{ij}$  and of the number of firms from country  $i$ ,  $N_i$ .<sup>6</sup>

In Appendix A1, we show that the transport costs affect the trade level negatively, that is that the partial derivative  $\frac{\partial Q_{ij}}{\partial t_{ij}} < 0$ . Considering that exports are declared net of transport costs, we obtain the total bilateral export value by aggregating each firm's export sales,  $r_{ij}^{fob}(m) = p_{ij}^{fob}(m)q_{ij}(m)$ , over all exporters from  $i$  to  $j$ :

$$\begin{aligned} EX_{ij} &= N_i \frac{L_j}{4\gamma} \int_0^{\hat{c}_j} (\hat{c}_j^2 - c_i^2(m)) g(c_i(m)) dc_i(m) \\ &= \frac{1}{4\gamma} N_i L_j \hat{c}_i^{-\delta} \underbrace{\left[ \frac{2}{2+\delta} (\hat{c}_j - t_{ij})^{2+\delta} \right]}_{\Phi(t)}. \end{aligned} \quad (8)$$

Equation (8) shows that the aggregate bilateral export values are characterised by a gravity-type relation: a positive impact on exports of the sizes of the two country,  $N_i$  and  $L_j$ , and negative impact of transport costs,  $t_{ij}$  (since  $\hat{c}_j > t_{ij}$ ). Furthermore, exports rise in the minimum (and average) productivity in the home country  $f(1/\hat{c}_i)$  and fall in the productivity in the partner country  $f(1/\hat{c}_j)$ . As a result of the additive nature of the transport costs, their effect on the export level is strongly interlinked with the partner country's productivity  $1/\hat{c}_j$ .

### 3.2 | The transport sector

As the transport sector for cross-border services typically consists of a few large companies, we impose an oligopolistic market structure. We assume that transport is a homogeneous service. Consequently, exporting firms base their decision for a service supplier on transport costs. To keep the model simple, we focus on differences in the aggregate pattern of bilateral transport costs between countries and model  $n^T$  symmetric firms in the transport sector. With  $I$  exporting

<sup>6</sup>The number of firms from country  $i$  that are active in country  $j$  can be expressed as the product of the share of exporters in the number of firms in  $i$ ,  $N_{ij} = \left( \frac{G(\hat{c}_j)}{G(\hat{c}_i)} \right) N_i = \left( \frac{\hat{c}_j - t_{ij}}{\hat{c}_i} \right)^\delta N_i$ .



and  $J$  importing countries, we assume that all  $I \times J$  bilateral trading routes are served by each transport firm. The total number of transport firms,  $n^T$ , is exogenously given.<sup>7</sup>

Transport firms choose their transport technology when starting to service a particular route. Like Yeaple (2005) and Bustos (2011), we simplify this choice by assuming that there are just two possible cost structures to choose from: technology  $H$  (with *high* variable costs,  $a^H$ , and low fixed costs,  $f^H$ ) and technology  $L$  (with *low*-variable costs,  $a^L$ , and high fixed costs,  $f^L$ ), that is  $a^H > a^L$  and  $f^H < f^L$ . Consequently, marginal costs of shipping one unit of a manufactured good between  $i$  and  $j$ ,  $a_{ij}^l$  with  $l = L, H$ , differ depending on the technology chosen. In addition to route-specific transport investments, marginal costs  $a_{ij}^l$  differ with regard to distance and other characteristics of the two trading countries.<sup>8</sup> The total cost function of a transport firm and its profit function are given by

$$A_{ij}(t_{ij}) = a_{ij}q_{ij}^T(t_{ij}) + f, \tag{9}$$

$$\pi_{ij}(t_{ij}) = t_{ij}q_{ij}^T(t_{ij}) - A_{ij}(t_{ij}), \tag{10}$$

where  $q_{ij}^T$  denotes the units shipped and  $t_{ij}$  is the price for the homogeneous transport service.<sup>9</sup> We obtain the corresponding supply,

$$q_{ij}^T = \left( \frac{t_{ij} - a_{ij}}{t_{ij}} \right) \varepsilon Q_{ij} = \left( \frac{t_{ij} - a_{ij}}{t_{ij}} \right) \varepsilon n^T q_{ij}^T, \tag{11}$$

with  $\varepsilon = - \frac{\partial Q_{ij}}{\partial t_{ij}} \frac{t_{ij}}{Q_{ij}}$  as the price elasticity of demand. Note that the supply of transport services,  $q_{ij}^T$ , increases in the transport price,  $t_{ij}$ , and the quantity of export by the manufacturing sector,  $Q_{ij}$ , which is the demand for transport services. With the demand (7) strictly falling and supply (11) strictly rising in the transport price,  $t_{ij}$ , there exists exactly one transport price level that clears the market for transport services. Equation (11) also shows that the output of a transport service supplier is negatively affected by the variable costs  $a_{ij}$ .

The second equation in (11) uses the fact that the transport service market must be cleared in equilibrium, hence  $Q_{ij}(t) = Q_{ij}^T = \sum_1^{n^T} q_{ij}^T(t_{ij}) = n^T q_{ij}^T$ . Solving the supply Equation (11) for the transport price,  $t_{ij}$ , yields the price as a function of the firms' costs,  $a_{ij}$ , the number of firms,  $n^T$ , and the demand elasticity,  $\varepsilon$ ,

$$t_{ij} = \frac{\varepsilon n^T}{\varepsilon n^T - 1} a_{ij}. \tag{12}$$

<sup>7</sup>The number of firms could be endogenized by introducing fixed cost of market entry in the transport sector,  $f_T$ . As long as we maintain the assumption that all routes are served by each transport firm, endogenous (derived) number of firms would not alter the results.

<sup>8</sup>Since all variables except the number of firms in the transport sector,  $n^T$ , depend on the chosen technology, we drop  $l$  hereafter.

<sup>9</sup>Transport costs in the manufacturing sector,  $t_{ij}$ , correspond to transport prices in the transport sector.

Knowing that in a symmetric equilibrium, every firm satisfies  $q_{ij}^T = Q_{ij}/n^T$  of the demand, we can rewrite transport firms' profits as

$$\pi_{ij} = (t_{ij} - a_{ij})q_{ij}^T - f = \underbrace{(t_{ij} - a_{ij})}_{\mu_{ij}} \frac{Q_{ij}}{n^T} - f, \quad (13)$$

where we define the mark-up  $\mu_{ij}$  as  $t_{ij} - a_{ij}$ . Without investment, firms use the 'high variable-/low fixed-costs' technology which is the standard transport technology. With this outline, we can now examine the incentive to invest in a variable-cost-saving transport technology for each route between country  $i$  and  $j$ . Equation (14) shows that the variable profits,  $\pi_{ij}^{\text{var}}$ , generated on route  $ij$  increase as the marginal costs of shipping between these two countries decline,<sup>10</sup>

$$\begin{aligned} \frac{d\pi_{ij}^{\text{var}}}{da_{ij}} &= \frac{\partial \mu_{ij}}{\partial a_{ij}} \frac{Q_{ij}}{n^T} + \frac{\partial Q_{ij}}{\partial a_{ij}} \frac{\mu_{ij}}{n^T} \\ &= \frac{Q_{ij} - (1+\epsilon)}{n^T} \frac{1}{\epsilon n^T - 1} < 0, \end{aligned} \quad (14)$$

Equation (14) states that the profit-growing effect of investing in advanced technologies increases with the export volume,  $Q_{ij}$ , of the manufacturing sector of country  $i$ . Thus, routes on which large volumes of goods are traded generate more additional profits if the variable costs of transportation,  $a_{ij}$ , decline.

The comparison of profits guides the transport firm's decision to invest in one of the two available technologies. Transport suppliers decide to invest in the advanced technology if the lower marginal costs generate sufficiently high variable profits to make up for the higher fixed costs. The discussion above reveals that this is more likely for transport routes with high trading volumes,  $Q_{ij}^H$  are traded already with the standard transport technology,

$$\frac{1}{n^T} \left[ (t_{ij}^L - a_{ij}^L) Q_{ij}^L - (t_{ij}^H - a_{ij}^H) Q_{ij}^H \right] > f^L - f^H \quad \text{if } Q_{ij}^H \text{ is large.} \quad (15)$$

Trading routes that generate more additional variable profits are more likely to jump the additional fixed costs hurdle  $f^L - f^H$ . On these routes, the introduction of the low-variable-costs technology is more likely. Since the technology choice affects route-specific prices, we expect lower transport prices on routes with large trade volumes.

$$t_{ij}^l = \begin{cases} \frac{\epsilon n^T a_{ij}^L}{\epsilon n^T - 1} & \text{for } Q_{ij}^H \text{ large} \\ \frac{\epsilon n^T a_{ij}^H}{\epsilon n^T - 1} & \text{for } Q_{ij}^H \text{ small.} \end{cases} \quad (16)$$

<sup>10</sup>See A2 for the derivation of this result.

Thus, given the technology choice by transport firms, transport costs differ for routes of similar distance and with similar other characteristics but different trade volumes. This implies that transport prices depend on trade volumes—in particular on exports—shipped by transport firms on behalf of and ordered by the manufacturing firms. In order to specify the variable costs, we rewrite the transport price Equation (12) as

$$t_{ij}^l = \frac{\varepsilon n^T a_{ij}^l}{\varepsilon n^T - 1} = \frac{\varepsilon n^T}{\varepsilon n^T - 1} \tau_{ij} \frac{w_i}{\phi_i I} \quad (17)$$

where  $\tau_{ij}$  denotes the unit cost function of the distance that must be overcome,  $w_i$  the wages in country  $i$  and  $\phi_i$  labour productivity in the logistics sector in  $i$ .  $I$  is a binary variable that catches the effect of the investment decision and takes the value of one (larger than one) without (with) investments.

#### 4 | ESTIMATING TRANSPORT COSTS: AN ILLUSTRATIVE EXAMPLE

The main insight from the theoretical model is that approximating transport costs by distance and other geography-related variables is not sufficient when dealing with a transport sector with optimising transport service suppliers. Hummels et al. (2009) point out that omitting market-power-related part of Equation (16),  $\frac{n^T}{(n^T - 1/\varepsilon)}$ , affects the estimation of distance costs. We add to

this finding the impact of technology choice on transport costs and therefore on trade values between two locations. Transport costs vary by distance *and* the endogenous technology choice.

We rely on price data of a specific segment of the transport sector: worldwide express delivery of 10 kg packages. As our transport price data do not relate to aggregate trade volumes between any two countries, we refrain from conducting a structural analysis and limit our analysis to the logistics market. We back our assumption of a (homogeneous) oligopoly by the empirical evidence from the dominant logistic firms UPS, FedEx and DHL, which set similar prices on the routes.<sup>11</sup> A ‘global oligopoly’ makes  $\frac{\varepsilon n^T}{\varepsilon n^T - 1}$  a constant factor, which does not contribute to explain the variation in prices between different routes. In the appendix, we include a competitive fringe in our model and show that the estimation equation is unaffected by this change.

Unfortunately, there is no observable information about route-specific costs and technology choices in the transport sector. Setting up an econometric model with an unobserved variable as the main variable of interest is not straight-forward matter, so we proceed in two steps. (i) We construct a generic data set close to the theoretical model from Section 3 and the structure of the empirical data. (ii) Using this generic data set, we reveal the technology choice of the transport sector. We search for the most appropriate set-up for the econometric model with an unobserved variable. Hence, we set up a numerical simulation exercise based on the theoretical model and use its insights to guide the empirical model specification and to deal with the problem of the unobserved investment decisions in the transport sector.

<sup>11</sup>Price schemes and pricing zones for worldwide transport services are provided by company's service and rate guides. For the USA, see UPS (<https://www.ups.com/us/en/shipping/rates.page>), FedEx (<https://www.fedex.com/en-us/shipping/current-rates.html>) and DHL ([http://www.dhl-usa.com/en/express/shipping/rate\\_and\\_transit\\_guide.html](http://www.dhl-usa.com/en/express/shipping/rate_and_transit_guide.html)).

## 4.1 | Generic data set

We estimate the price equation of the transport firms (17). Sample size and structure of the generic data set is chosen to match the size of the empirical data. We randomly choose latitudes and longitudes for 30 exporting (reporting country  $i$ ) and 61 importing (receiving country  $j$ ) countries, from which we compute a matrix of distances between any two of these countries. We employ the great circle distance formula, which uses the radian values of the latitude and longitude. The randomly assigned population size variables ( $pop_i > 500$ ,  $pop_j > 500$ ) for each country are drawn from a uniform distribution with mean 1000. Country-specific (average) marginal cost threshold with mean 2 in the first year is strongly related to  $\hat{c}_i$  in Equation (8).<sup>12</sup> Productivity in the transport sector and two error terms,  $u_{ex}$  and  $u_t$ , are drawn from an uniform distribution with mean 1. The error terms are added to export values and transport costs, which are computed according to (8) and (17). We match the structure of the empirical data (i.e. panel data with 4 years) and construct four waves for a panel simulation. For each country and year, we draw a growth rate for transport sectors' productivity from a normal distribution (both with a mean of 2% and standard deviation of 11%, given by the empirical data).<sup>13</sup>

### 4.1.1 | Transport prices

We ignore the market power term of Hummels et al. (2009) in Equation (16) and assume that transport prices for supplying the transport service depend on route-specific marginal costs, the technology choice and an error term. To approximate the route-specific marginal costs in the logistics sector, we use the bilateral distance between two countries,  $dist_{ij}$ , the GDP per capita in the exporting country as a proxy for wages  $w_i$ ,  $gdp - cap_i$  and labour productivity in the logistics sector of country  $i$  for  $\phi_i$ ,  $prod - tr_i$ . According to (17), we construct transport prices as

$$t_{ij} = 0.05 \times dist_{ij}^{0.2} \times gdp - cap_i / (prod - tr_i \times I_{ij}) \times u_t, \quad (18)$$

where the technology choice,  $I_{ij} = 1$ , is assumed identical for all trading pairs before investment.  $u_t$  is an error term. We set the constant to 0.05 and the exponent to 0.2 as in Hummels et al. (2009). We expect distances and GDP per capita to have a positive effect on transport prices, while the effect of labour productivity should be negative.

### 4.1.2 | Exports

Equation (8) suggests that exports from country  $i$  to country  $j$  are a positive function of the two country sizes,  $gdp_i$  and  $gdp_j$ , country  $i$ 's cost threshold,  $gdp - cap_i$ , and a negative function of the transport costs,  $t_{ij}$ . We construct the bilateral export according to Equation (8) setting  $\gamma = 5$  and

<sup>12</sup>Size variables  $gdp$  and per-capita variables  $gdp-cap$  are calculated using  $gdp = pop/marginal\ costs * 10$  and  $gdp-capita = gdp/pop$ .

<sup>13</sup>Descriptive statistics of the generic data set are given in Table C1 in the appendix. All results are obtained by repeating the numerical simulation 10,000 times.

$\delta = 1.6$ . The number of firms  $N_i$  is approximated as function of the population using  $N_i = \frac{100+L_i}{6} u_i$ , where  $u_i$  is a random term with mean one.

### 4.1.3 | Technology choice

The technology choice depends on the aggregated export value of the manufacturing firms. To reflect the endogenous investment decision, we introduce two alternatives for the technology choice: (i) a discrete technology choice and (ii) a continuous investment function.

In the discrete technology choice, logistics firms can choose from two technologies with high or low-variable costs,  $H$  and  $L$ . The low-variable-cost-strategy prevails if transport volumes are large:

$$I_{ij}^d(\text{exports}_{ij}) = \begin{cases} 1 & \text{if } \text{export}_{ij} \leq 8000 \\ 3 & \text{if } \text{export}_{ij} > 8000. \end{cases} \quad (19)$$

Thus, there is an export threshold according to which the investment indicator either realises  $a^H$  or  $a^L$ . The threshold is chosen such that about 10% of the routes qualify for cost-cutting investments. Modelling the investment decision as a discrete choice variable closely reflects the theoretical set-up.

In the continuous technology choice, we assume a continuum of investment opportunities related to the different levels of marginal costs such that higher investment induces lower costs which pay off on routes with high bilateral trade values:

$$I_{ij}^c(\text{exports}_{ij}) = (1 + \text{export}_{ij}/1500)^{0.35}. \quad (20)$$

The inverse relationship between exports and marginal costs is given by  $a_{ij}(\text{exports}_{ij}) = \frac{\tau_{ij}W_i}{\phi_i I_{ij}}$ , where  $a_{ij}'(\cdot) = -0.35(1 + \text{export}_{ij}/1500)^{-0.65} < 0$ . The parameters of the investment function are chosen to match the minimum, the mean and the maximum of the discrete case closely (see Table C1).

## 4.2 | Econometric challenges

By construction, the generic dataset rules out heteroskedasticity in the error terms and zero trade flows between any pair of countries. We log-linearize Equation (18) as

$$\ln(t_{ij}) = \beta_0 + \beta_1 \ln(\text{dist}_{ij}) + \beta_2 \ln(\text{gap} - \text{cap}_i) - \beta_3 \ln(\text{prod} - \text{tr}_i) - \beta_4 \ln(I_{ij,t}(\text{exports}_{ij,t})) + \mu_t + \ln(u_{ij,t}), \quad (21)$$

where  $\mu_t$  denote year dummies. Note that using the empirical data, the investment decision,  $I_{ij,t}$ , is unobserved and leads to a bias from two sources: the omitted variable of investment decision and the endogeneity of the technology choice.

### 4.2.1 | Omitted investment decision variable

The first problem results from the correlation between the omitted variable,  $I_{ij}$ , and the explanatory variables,  $dist_{ij}$ ,  $gdp - cap_i$  and  $prod - tr_i$ . Hence,  $dist_{ij}$ ,  $gdp - cap_i$  and  $prod - tr_i$  are not orthogonal to the error term when estimating (21). The direction of the bias depends on the sign of the covariance between the omitted variable  $I_{ij}$  and the regressors. Since the relationship between distance and transport prices is negative, the  $\beta_1$  coefficient of  $dist_{ij}$  is biased upward when omitting  $I_{ij}$ .<sup>14</sup> The same applies for the  $\beta_2$  coefficient of  $gdp - cap_i$ , while the  $\beta_3$  coefficient of  $prod - tr_i$  is upwards biased in absolute terms. To deal with the bias, we include the top 150 (8.3% of all routes), top 250 (13.9%) and top 350 (19.4%) dummy. While these dummy variables are closely related to the investment indicator—as investments pay off only on trade-intensive routes—reducing the cost and the price of the transport service does not change the ranking of bilateral export relationships. Routes with the largest trade values have on average lower trade costs.

### 4.2.2 | Endogeneity of technology choice

The second problem results from the fact that the investment indicator is a function of the route-specific exports and thus not merely a function of both reporting and receiving countries' economic sizes, distance, GDP per capita and labour productivity in the logistic sector of country  $i$ . Instead, it reflects an endogenous decision by transport service suppliers, which affects the level of their marginal costs. As much as the investment decision depends on exports, transport costs depend on the technology choice which affect the transport costs and thereby the exports. A single equation framework as in (21) requires a proxy variable for the unknown investments such as exports, which has to be appropriately instrumented. By construction of our simulated data, both countries' economic size variables, reporting countries' GDP per capita and transport sectors' productivity are exogenous in the estimation of the export Equation (8) and serve as valid instruments for exports.

## 4.3 | Results of the estimation using the simulated data

We estimate six different specifications of Equation (21) (i.e. model specification (i)–(vi)) and report the results for the discrete and continuous case in Tables 2 and 3, respectively. We repeat the construction of the data and the estimation of the transport cost equation 10,000 times to ensure that the results are not driven by outliers of the random variables. Column (i) of both tables presents the results when omitting  $I_{ij}$  from Equation (18). We address the omitted variable bias with proxies for the top 150, top 250 and top 350 export routes in columns (ii)–(iv). Column (v) presents the results with an investment indicator, assuming the investment indicator to be an observable variable. By using the knowledge of  $I_{ij}$ , there is no omitted variable and no endogeneity bias and we refer to this specification as the 'true model'. Finally, we proxy the omitted variable by exports and address the endogeneity with instrumental variables. We present the results of an IV regression in column (vi).

<sup>14</sup>If we do not control for investment, the coefficient of  $[Cov(dist_{ij}, I_{ij}) / Var(dist_{ij})]$  gives the magnitude of the bias of  $\beta_1$ , see Wooldridge (2002).

TABLE 2 Omitted variable bias: The discrete investment case

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
	Omitting	Proxy	Proxy	Proxy	Investm.	IV
	$I_{ij}^d$	Top 150	Top 250	Top 350	$I_{ij}^d$	Exports <sub>ij</sub>
Dependent variable: Bilateral transport costs $t_{ij}$						
$dist_{ij}$	.276 (.013)	.210 (.006)	.213 (.008)	.218 (.010)	.198 (.002)	.177 (.010)
$cap - gdp_i$	1.573 (.059)	1.088 (.028)	1.088 (.034)	1.122 (.039)	.982 (.013)	.788 (.072)
$prod - tr_i$	-1.301 (.052)	-1.035 (.028)	-1.027 (.033)	-1.039 (.039)	-.991 (.012)	-.714 (.057)
Top 150		-.776 (.026)				
Top 250			-.536 (.025)			
Top 350				-.403 (.021)		
$I_{ij}$					-1.03 (.005)	
Exports <sub>ij</sub>						-.111 (0.009)
$R^2$	.52	.76	.69	.64	.92	.60

Note: Standard errors in parentheses. Estimations include unreported year dummies.

Source: Generic data. Own calculations.

Omitting  $I_{ij}$  from Equation (21), the effect of distance, GDP per capita and labour productivity are too large in both the discrete and the continuous case. In the discrete case (see Table 2), the distance coefficients are close to the estimates in the 'true model' when using proxies for the top 150, 250 and 350 export routes. In the continuous case (see Table 3), the IV regression with the instrumented export variable works better (comparing the biases in the distance coefficients or the  $R^2$ ) than any of the dummy variable models. Next, test statistics reveal that exports are endogenous. The null hypothesis is rejected frequently at the 5% level of significance with an average  $p$ -value = .12 for the discrete case and average  $p$ -value = .097 for the continuous case out of 10,000 repetitions. As both exogenous economic size variables ( $gdp_i$  and  $gdp_j$ ) are jointly required to instrument bilateral exports, overidentification test results are likely to be spurious and of limited use.<sup>15</sup> Finally, test statistics reject the null hypoth-

<sup>15</sup>Indeed, test statistics rejects the validity of the instruments in about 89.2% of all repetitions in the case of the discrete investment indicator (average  $p$ -value = .043) and 60.8% in the case of the continuous investment function (average  $p$ -value = .161). As Wooldridge (2002): 221 remarks: 'Necessary but not sufficient for overidentification is  $J_1 > G-1$  (Number of restrictions is larger than the number of endogenous variables). It is possible that  $J_1$  is strictly greater than  $G-1$  but the restrictions are such that dropping one restriction loses identification, in which case the equation is not overidentified'. Testing two (instead of jointly used) economic size variables as instruments for bilateral exports likely explains the frequent rejection of the overidentification test.

TABLE 3 Omitted variable bias: The continuous investment case

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
	Omitting	Proxy	Proxy	Proxy	Investm.	IV
	$I_{ij}^c$	Top 150	Top 250	Top 350	$I_{ij}^c$	Exports <sub>ij</sub>
Dependent variable: Bilateral transport costs $t_{ij}$						
$dist_{ij}$	.302 (.007)	.269 (.005)	.258 (.005)	.251 (.005)	.193 (.002)	.208 (.005)
$cap-gdp_i$	1.774 (.038)	1.525 (.031)	1.432 (.028)	1.366 (.027)	.944 (.014)	.972 (.040)
$prod-tr_i$	-1.510 (.037)	-1.374 (.030)	-1.317 (.028)	-1.273 (.026)	-.963 (.013)	-.931 (.031)
Top 150		-.397 (.011)				
Top 250			-.377 (.009)			
Top 350				-.363 (.008)		
$I_{ij}$					-1.072 (.008)	
Exports <sub>ij</sub>						-.108 (.005)
$R^2$	.72	.79	.82	.83	.91	.84

Note: Standard errors in parentheses. Estimations include unreported year dummies.

Source: Generic data. Own calculations.

esis of weak instruments by an average minimum eigenvalue of 199 in the discrete case and 225 in the continuous case.<sup>16</sup>

Turning to the goodness-of-fit of our simulations, we obtain for the discrete case the highest  $R^2$  on average for the regression with the dummy variable top 150 (8.3% of all bilateral trade routes), which comes closest to the 'true model' (6.6% of all trade routes with investments). For the continuous case, the IV regressions explain most of the variation of the transport prices. Instrumenting exports gives a higher  $R^2$  than using any of the proxy variables, and coefficients of both distance and GDP per capita are closer to the 'true model' than in any other specification.

Equation (19) assumes that variable transport costs are reduced to a third. This reduction is arbitrary. As a robustness test, we run (and add to the Appendix) two simulations, which assume a variable-cost reduction to either a half or a quarter (of the pre-investment), for both the discrete and continuous investment function. We find almost identical coefficients and qualitatively the same results compared to Tables 2 and 3, respectively. Results are reported in Tables B1–B4 in the Appendix.

To sum up, the best strategy for our empirical set-up is to include investment dummies and to instrument export to deal with the omitted variable bias and the endogeneity problem.

<sup>16</sup>The minimum eigenvalue of our 10,000 replications is 31.0 in the discrete and 34.9 in the continuous case. Both exceed the critical value of 18.39 for an accepted 5% bias of a regression with one endogenous regressor and five instruments.



## 5 | ESTIMATING TRANSPORT COSTS: THE EMPIRICAL CASE

We apply the strategy from the previous section to empirical data. We combine UPS transport prices from different years with bilateral trade data, data on GDP and GDP per capita, and geodesic distances (Table C2 in the appendix presents descriptive statistics). We present two kinds of empirical results: (i) estimates based on OLS regressions as our benchmark and (ii) Poisson regressions.<sup>17</sup> We report results that are robust to model specifications and different subsets of data.

### 5.1 | Data

#### 5.1.1 | Transport prices

We built a new data set by collecting price data from UPS for shipping 10 kg 'Express Savers' packages between countries. We have collected transport prices for 30 reporting countries trading with 61 partner countries for the years 2010, 2013, 2017 and 2019. We convert transport prices in local currency to US\$ by the use of exchange rates (period averages) from OECD countries' national accounts (OECD, 2021a). We use UPS price data as representative data for the transport sector because price and pricing scheme of the main competitors are very similar.<sup>18</sup>

The bilateral transport prices are grouped by transport firms in few price zones as a geographical unit with similar pricing schemes. Accordingly, countries included in the same price zones have the same prices: 14 different export prices at most are reported for 60 different destinations for shipments. Pricing zones are arranged along several criteria, where distance is an important but not the only criterion.<sup>19</sup> There are significant differences between (exporter and importer) transport prices for shipments in opposite directions depending on packages being sent or received (shown by Table C5 in the appendix). Shipping 10 kg Express Saver package either from or to Mexico, for example costs € 313.90 for German exporters or € 263.30 for German importers. In contrast, an exporter in Mexico pays US\$ 211.22 for sending a shipment to Germany (€ 188.59 by the use of the average 2019 exchange rate), while shipments from Germany costs a Mexican importer US\$ 468.20 (€ 418.04).

#### 5.1.2 | Exports and GDP

We combine UPS transport prices charged on different routes with bilateral trade and GDP data. The OECD ICTS database (OECD, 2021d) provides bilateral trade data in current US\$ for OECD countries. We use the current exchange rate from the OECD (OECD, 2021a) and the US-GDP deflator of the World Development Indicators (WDI) database (World Bank, 2020) to convert current US\$ export flows into constant US\$. As a proxy for marginal costs, we use GDP per capita in constant US\$ from the WDI database (World Bank, 2020). For labour productivity

<sup>17</sup>Following Silva and Tenreyro (2006), we use the poisson estimator, because we cannot rule out heteroskedastic error terms when working with empirical data and we allow for a correct treatment of zero trade flows (even though the number of zeros is very low in our sample).

<sup>18</sup>Table C3 in the appendix shows an almost perfect positive correlation for 1740 bilateral trading routes between transport prices of UPS, DHL and FedEx for the year 2020. Moreover, correlation coefficients between 'Express' and 'Express Saver' UPS prices for both sending (*ex*) or receiving (*im*) 10 kg packages are close to one.

<sup>19</sup>Table C4 and Figure C1 in the appendix shows Germany's pricing scheme and pricing zones.

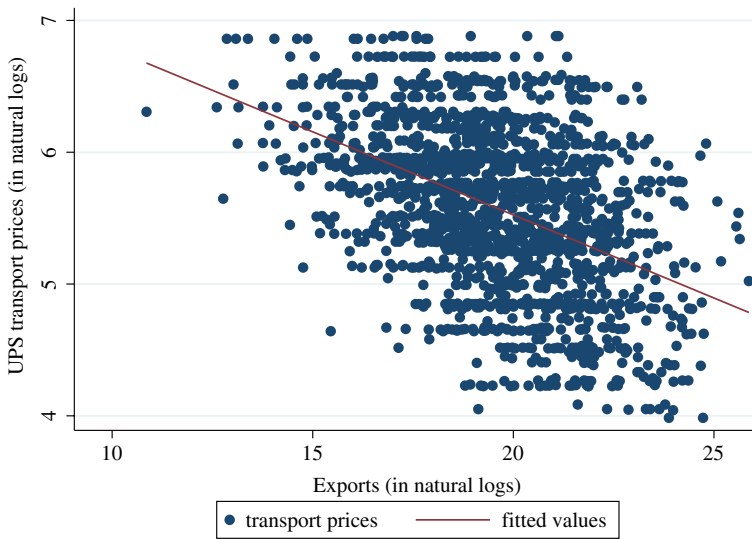


FIGURE 1 UPS transport prices and exports (2017). [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

in the transport sector, we include transport sectors' GDP per employee in constant US\$ from the OECD national accounts (OECD, 2021b,c). Without missing data, our data set would contain  $(30 \times 61 - 30) \times 4 = 7200$  observations. However, a few missing observations in either the trade or the transport price data reduce the sample to 7072 observations. Figure 1 plots bilateral export values and transport prices for each country pair in our sample for 2017. Not surprisingly, the downward sloping fitted line confirms that the higher the export values, the lower the transport prices.

As there is no information available regarding specific investments by the transport sector, we are unable to observe directly the impact of investments on transport prices. To deal with the problem of the omitted investment decision variable, we construct a dummy for the top 150, top 250 and top 350 (out of 1800) bilateral export values for each year. Controlling for the endogeneity of exports, we use bilateral exports instrumented by both countries' GDP in constant US\$ from the WDI database (World Bank, 2020).

### 5.1.3 | Distances

We use geodesic distances between the two most populated cities in each country provided by GEODIST database from CEPII (2020) (see CEPII (2020)). However, the choice of location within countries matters: In the case of Germany, choosing Frankfurt (as the main logistics hub) instead of Berlin (as the most populated city) significantly affects the distances between European countries (as shown by Table C4 in the Appendix), while Germany's' maritime distances differ even more from geodesic distances.<sup>20</sup> In our data, however, sea transport is no

<sup>20</sup>The overland distance to France, for example, shrinks to about one half (Frankfurt–Paris 480 km vs. Berlin–Paris 878 km), whereas the distance to Poland almost doubles (Frankfurt–Warsaw 890 km vs. Berlin–Warsaw 515 km). In the case of maritime distances, the 'German location' would be Hamburg, the 'French location' either Marseilles (France's largest port, 4210 km away from Hamburg) or Dunkirk (second largest port, 646 km away). Moreover, the shipping distance from Germany to China (Shanghai) (19,628 km) is more than twice the geodesic distance (8818 km). Other countries do not even have sea access. The correlation between the geodesic distances and the maritime distances of all partner countries with sea access is 0.88 with a rank correlation of 0.86.

option, while logistics firms chose a mix of mode logistics for their door-to-door offer (like plane, train, truck and van). Thus, bearing in mind the data limitation of both transport prices and distances, we cannot expect an equally high fit as in the previous section with the simulated generic data.

## 5.2 | Main results

We start by estimating transport prices using the single equation approach with robust (clustered) standard errors as the benchmark. Table 4 shows the OLS and IV estimation of transport prices as a function of distance, GDP per capita, labour productivity, investment dummies (top 150, top 250 and top 350) and instrumented exports for different model specifications (i)-(v). The results of Poisson estimations are presented in Table 5.

### 5.2.1 | OLS estimation: (i)-(iv)

The OLS results indicate that UPS sets higher prices on more distant locations. The impact of distance on transport prices, however, is moderate. Transporting goods between countries that are 10% farther away from each other is between 1.5% and 1.8% more expensive. This result is in line with Clark et al. (2004) and other empirical estimations of transport cost equations that do not control for route-specific investment. The coefficient of GDP per capita is smaller but also significant at the 1% significance level. As expected, the coefficient of labour productivity is negative at least at the 5% significance level. Exporters from high-income countries pay, *ceteris paribus*, higher transport prices, while higher labour productivity reduces transport prices.

Since we cannot observe investments in the transport sector directly, we follow the strategy outlined in Section 4 and add to our baseline specification different investment dummy variables. In columns (ii)-(iv), we include three dummy variables for the top 150, top 250 and top 350 trade routes as proxies for infrastructure investment. All three proxy variables have a significantly negative impact: all else being equal, highly trafficked trading routes have lower the transport prices. Exporters trading on the busiest routes enjoy, on average, lower transport prices between 25% and 33%.

### 5.2.2 | IV estimation: (v)

Assuming a more continuous investment function, we include exports as an explanatory variable and report the results of an IV estimation in column (vi). Even though we introduce exports with a one year lag, the vast evidence on the gravity model suggests that endogeneity is likely to be present.<sup>21</sup> Together with bilateral distance, GDP per capita and labour productivity of the reporting country as exogenous regressors in Equation (21), we instrument bilateral exports by both reporting and partner countries' GDPs.

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<sup>21</sup>Consequently, a consistent IV estimation of transport prices requires that exports are appropriately instrumented. Valid instruments for exports must fulfil two criteria: first, they need to be independent from the residuals of the transport price, and second, they need to be sufficiently correlated with the included endogenous regressor.

TABLE 4 OLS estimation of transport prices

	(i)	(ii)	(iii)	(iv)	(v)
	Omitting	Proxy	Proxy	Proxy	IV
	$I_{ij}$	Top 150	Top 250	Top 350	Exports $_{ij}$
Dependent variable: Bilateral transport costs $t_{ij}$ (in logs)					
$dist_{ij}$	.1827*** (.0087)	.1649*** (.0084)	.1626*** (.0084)	.1582*** (.0088)	.1425*** (.0052)
$gdp-cap_i$	.1281*** (.0369)	.1427*** (.0369)	.1484*** (.0369)	.1435*** (.0371)	.1143*** (.0216)
$prod-tr_i$	-.0989** (.0440)	-.1030** (.0430)	-.1099*** (.0426)	-.1057** (.0428)	-.0691** (.0275)
Top 150		-.3345*** (.0294)			
Top 250			-.2795*** (.0254)		
Top 350				-.2470*** (.0231)	
Exports $_{ij}$					-.0539*** (.0028)
Endog. test					17.033
$p$ -val.					0
Overid. test					77.226
$p$ -val.					0
Underid. test					5227.877
$p$ -val.					0
Weak id. test					1.10E+04
$p$ -val.					0
No. of obs.	7012	7012	7012	7012	6946
$R^2$	.272	.302	.304	.304	.310

Note: The single equation estimations are reported with cluster-robust standard errors in parentheses with significance at the \*\*\* $p < .01$ , \*\* $p < .05$ , \* $p < .1$  level. Estimations include unreported constant terms and time dummies.

Source: Dataset of transport prices (UPS, 2020), geodesic distances (CEPII, 2020), bilateral export data (OECD, 2021d), GDP data (World Bank, 2020) and labour productivity (OECD, 2021b, 2021c). Own calculation.

Indeed, the null hypothesis of the endogeneity test (by the difference of two Sargan–Hansen statistics) states that ‘bilateral exports can be treated as exogeneous’ and is strongly rejected. Equation (21) must therefore be estimated by an IV estimation. The weak identification test (by Cragg–Donald F statistic, critical values by Stock and Yogo (2005)) shows that the excluded instruments are sufficiently correlated with bilateral exports, while the underidentification test (by Kleibergen–Paap statistic) confirms that the model is identified. Both tests reject the null hypothesis. As already discussed in the case of the exogenous instruments and the generic dataset, the

TABLE 5 Poisson estimation of transport prices

	(i)	(ii)	(iii)	(iv)	(v)
	Omitting	Proxy	Proxy	Proxy	IV
	$I_{ij}$	Top 150	Top 250	Top 350	Exports $_{ij}$
Dependent variable: Bilateral transport costs $t_{ij}$ (in levels)					
$dist_{ij}$	.1627*** (.0080)	.1482*** (.0079)	.1457*** (.0079)	.1419*** (.0081)	.1317*** (.0084)
$gdp-cap_i$	.1408*** (.0310)	.1529*** (.0309)	.1583*** (.0309)	.1549*** (.0310)	.1193*** (.0313)
$prod-tr_i$	-.0854** (.0401)	-.0895** (.0394)	-.0959** (.0391)	-.0932** (.0391)	-.061 (.0392)
Top 150		-.3379*** (.0300)			
Top 250			-.2779*** (.0259)		
Top 350				-.2420*** (.0233)	
Exports $_{ij}$					-.0551*** (.0055)
No. of obs.	7012	7012	7012	7012	6953
$R^2$	.205	.230	.233	.234	.242

Note: The single equation estimations are reported with cluster-robust standard errors in parentheses with significance at the \*\*\* $p < .01$ , \*\* $p < .05$ , \* $p < .1$  level. Estimations include unreported constant terms and time dummies.

Source: Dataset of transport prices (UPS, 2020), geodesic distances (CEPII, 2020), bilateral export data (OECD, 2021d), GDP data (World Bank, 2020) and labour productivity (OECD, 2021b, 2021c). Own calculation.

sufficiency criterion for overidentification is not met if two (size) variables are only valid as joint instruments. Testing two (instead of jointly used) economic size variables explains the rejection the null hypothesis of overidentification by Hansen's J test. Hence, we keep both countries' GDP as valid instruments for bilateral trade.<sup>22</sup>

The IV estimation results in column (v) are close to the single equation estimation results presented in columns (i)-(iv). However, the distance coefficient is considerably lower than in the baseline estimation equation (i) where we omit the investment decision. We find that a country pair with exports 10% above the average enjoys 0.54% lower transport prices. These results are in line with Skiba (2007)'s estimation based on a data set of maritime transport costs, which find an average reduction of 0.6% with a 10% export increase.

<sup>22</sup>The IV estimation results of Table 4 are robust to a different set-up of instruments and based on our previous discussion using the generic data. We tested potential miss specifications by including 'population size lags of both trading partners' GDP', 'reporting and receiving countries' GDP per capita', 'common language dummy', 'country fixed effects' or 'time effects' to the potential set of instruments. With the exception of both countries' population, we find that Hansen's J test statistics worsened and instruments are rejected. We conclude that it is not the instrument but its joint use that yields the rejection.

### 5.2.3 | Poisson estimation: (i)-(vi)

Poisson estimation results are reported in [Table 5](#) and are comparable to the OLS and IV estimation results in [Table 4](#). In line with the findings of Silva and Tenreyro (2006), the coefficients for distance are slightly below the OLS and IV estimates for equation (i)-(v). Bilateral distance remains a strong predictor of transport prices, even though there is no 'exclusive' relationship. Instead, infrastructure investments approximated by dummies for the top trading routes are significant explanatory factors. The same applies to the coefficient of the instrumented export values in column (v).

## 5.3 | Robustness checks

### 5.3.1 | Time-varying country dummies

We repeat the OLS estimations with time-varying country dummies for both reporting and partner countries to account for route-specific rather than general (country-specific) infrastructure investment  $I_{ij,t}$  (see Donaubaauer et al. (2018)). As shown in [Table D1](#) in the appendix, we obtain qualitatively the same significant results at least for the (higher) distance coefficient. Together with time-varying country effects, we refrain from including country-specific variables like GDP per capita and labour productivity. Again, selecting the top bilateral export routes (*top 150*, *top 250* and *top 350*) has a negative impact on transport prices. The coefficients of the investment dummy variables are less than half the size compared to [Table 4](#), while the coefficient of instrumented exports remains almost unchanged. Not surprisingly, the inclusion of time-varying country dummies increases the  $R^2$  to around 0.90 as most of the transport price variation is captured by countries' time-varying fixed effects.

### 5.3.2 | Trade specifications

Transport service suppliers like UPS do not offer transport for all kinds of goods. Cross-border transport of certain raw materials hinges on the availability of a very specific infrastructure such as pipelines, oil tankers or special ships or wagons to transport cars or livestock. To account for the fact that the collected UPS transport prices may not apply to all goods, we repeat the OLS and IV estimations in [Table 4](#) for two restricted samples. We construct two samples which exclude some groups of goods: In the large sample, we exclude trade in petroleum, gas and electric current from total bilateral exports. In the small sample, we additionally exclude goods that might have special transportation requirements, such as animals and perishable foods, chemicals, machinery and vehicles.<sup>23</sup> [Table D2](#) in the appendix shows that the coefficients are, in fact, very close to the main results reported in [Table 4](#).

<sup>23</sup>This corresponds to D01T03 'Agriculture, forestry and fishing', D05T08 'Mining and quarrying', D19T22 'Chemicals, rubber, plastics and fuel products', D29T30 'Transport equipment', D35 'Electricity, gas, steam and air conditioning supply' of the International Standard Industrial Classification (ISIC) Rev. 4, respectively.

### 5.3.3 | Trade by transportation mode

We separate trade volumes by transportation mode and account for the fact that express delivery is likely to be done by air transportation. Eurostat offers bilateral data on Extra-EU trade since 2000 by mode of transport (NSTR) (Eurostat, 2022), which we combine with the UPS price data at hand. Adjusting our panel according to the Extra-EU trade pattern, bilateral trade relationships reduces to 19 (out of 30) reporting EU countries and 42 (=61–19) non-EU partner countries. In the absence of missing data, our data set is reduced by more than half and would contain  $(19 \times 61 - 19) \times 4 = 3192$  observations. However, missing data in the bilateral trade pattern reduce the size of the panel to 2807 observations at most.

We repeat our OLS estimations of Table 4 and focus on top bilateral trading routes (i.e. *top 150*, *top 250*) and instrumented bilateral exports ( $\text{export}_{ij}$ ). Top trading routes and instruments refer to values from air transportation and total trade. Table D3 in the appendix shows that the coefficients are, in fact, very close comparing air transportation and total trade (i.e. column (i)–(iii) vs. column (iv)–(v), respectively). In particular, top trading routes for EU reporting countries are the same (with identical coefficients) for both trade volume specifications (i.e. column (i) vs. column (iv) for *top 150*, respectively). The IV estimations report coefficients of instrumented export values to be significantly negative and almost the same in magnitude comparing air transportation and total trade, while the bilateral distance coefficient is almost half size in the case of total trade (i.e. column (iii) and column (v)).

### 5.3.4 | Trade imbalances

Moreover, we add to our benchmark estimations bilateral trade imbalances ( $(\text{exports} - \text{imports}) / \text{trade values}$ ) and a trade dummy (with value one for net importer and zero for net exporter). Table D4 in the appendix shows that trade imbalances do not drive our results of the main variables in terms of coefficients, sign and significance, but reveals that a trade surplus indeed increases significantly exporting countries' transport prices. This positive impact is in line with Brancaccio et al. (2017)'s results on the effect of trade imbalances on transport costs.

## 6 | TRANSPORT SECTOR INVESTMENT AND GLOBALISATION

Our empirical results show that distance affects transport prices positively and that bilateral trade value have a strong price-reducing-effect. High trade volumes result in investment in new, often large-scale, trade-enhancing transport technologies. Even though the debate on the 'distance puzzle' or the 'missing globalisation puzzle' (Coe et al., 2007) states that investment in new technologies reduces transport costs, technology choices (of the transport sector) are rarely included in empirical studies. To study this source of falling transport costs, we propose a model of international trade augmented by a transport sector, where transport prices are set endogenously and firms are able to choose among different route-specific technologies. Our set-up allows us to specify transport costs as a function of distance, geography-related variables and technology choices of the transport sector. The inclusion of transport sector investment in the analysis of international trade is useful in illuminating three crucial issues: (i) the driving force of globalisation, (ii) the distance puzzle and (iii) trade and development.

## 6.1 | Globalisation (i)

Increasing trade leads to falling transport prices, which in turn stimulate trade. We think that globalisation can be explained by an investment-induced decline in transport prices, which is endogenous and the result of the profit-maximising behaviour in the transport sector. If we correctly model the production function of the transport sector, infrastructure investment is the main source of differences in transport prices among trading routes of similar distances.

## 6.2 | Distance puzzle (ii)

Our study is related to the distance puzzle. We observe that omitting the investment decision variable biases the distance coefficient in the transport price. Such a bias depends on the correlation between distance and investment decision. The distance coefficient would be unbiased only if investment decisions of the transport sectors are unrelated to distance.

## 6.3 | Trade and development (iii)

The interdependence between transport prices and trade is important for developing countries. Any change that leads to an increase in trade has the potential to reduce transport prices and vice versa: A regional trade agreement, for instance, might induce more trade and therefore reduce transport prices, pushing trade integration to a next level. Moreover, an environment supportive for investment in the transport sector leads to investment in modern logistics' technologies and lowers transport prices, which again increases trade.

## 7 | CONCLUSIONS

We propose a model of international trade with a transport sector in which transport prices are set endogenously and affect bilateral export levels between countries. By setting up a theoretical framework with a manufacturing and a transport sector, we show that (i) suppliers invest in modern transport technology on heavily trafficked trade routes when optimising transport services, (ii) the technology choice affects transport prices via the marginal costs of supplying transport services and (iii) it is not sufficient to approximate transport costs by distance and geography-related variables alone.

Using a generic data set, we illustrate the bias of the distance coefficient if technology choices of the transport sector are not included and show that using proxy variables and instrumental variable techniques are appropriate for dealing with the problem of omitted variables and endogeneity. Relying on a data set of UPS transport prices, we find that instrumented exports (as a proxy for investment technology) have a significant negative effect on transport prices. In particular, our estimates show that trading routes with exports 10% above the average of all trade pairs enjoy almost 0.6% lower transport prices. We find that adding technology choice in the transport sector is useful in the discussions on the drivers of globalisation, the distance puzzle, and trade and development.



## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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**APPENDIX A**

**A.1 | THEORETICAL APPENDIX**

**A.1.1. | Derivation of the negative slope of the demand function**

Demand is given by (7) which can be written as

$$Q_{ij} = \hat{c}_i^{-\delta} \frac{N_i L_j}{2\gamma} (\hat{c}_j - t_{ij})^\delta \left( \frac{1}{1+\delta} \hat{c}_j - \frac{\delta+2}{\delta+1} t_{ij} \right) \tag{A1}$$

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

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

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

We use the partial derivative to derive  $\varepsilon$  as  $\varepsilon = - \frac{\partial Q_{ij}}{\partial t_{ij}} \frac{t_{ij}}{Q_{ij}} = \left( \frac{\delta}{\hat{c}_j - t_{ij}} + \frac{2+\delta}{\hat{c}_j - (2+\delta)t_{ij}} \right) t_{ij}$ . Thus,

$$\begin{aligned} \frac{\partial Q_{ij}}{\partial t_{ij}} &= - \frac{\varepsilon}{t_{ij}} Q_{ij}. \text{ Note that the elasticity of demand increases in } t_{ij}, \text{ since} \\ \frac{\partial \varepsilon}{\partial t_{ij}} &= \frac{\delta(\hat{c}_j - t_{ij}) + t_{ij}\delta}{[\hat{c}_j - t_{ij}]^2} + \frac{(2+\delta)[\hat{c}_j - (2+\delta)t_{ij}] + (2+\delta)^2 t_{ij}}{[\hat{c}_j - (2+\delta)t_{ij}]^2} > 0. \end{aligned}$$

**A.1.2. | Derivation of the negative slope of the profit function**

The change in the variable profits  $\pi_{ij}^{var}$  of a transport firms in reaction to a cost reduction has two

components: (i) the mark-up  $\mu_{ij} = t_{ij} - a_{ij}$  decreases and (ii) the demand  $Q_{ij}$  increases. Thus,

$$\begin{aligned} \frac{\partial \pi_{ij}^{var}}{\partial a_{ij}} &= \frac{\partial \mu_{ij}}{\partial a_{ij}} Q_{ij} / n^T + \frac{\partial Q_{ij}}{\partial a_{ij}} \frac{\mu_{ij}}{n^T}. \text{ We derive the two effects in turn. We write the mark-up } \mu \\ \mu_{ij} &= \frac{1}{\varepsilon n^T - 1} a_{ij}. \end{aligned}$$

$$\text{First component: } \frac{\partial \mu_{ij}}{\partial a_{ij}} \frac{Q_{ij}}{n^T} = \frac{1}{\varepsilon n^T - 1} \frac{Q_{ij}}{n^T} > 0$$

The second part involves the partial derivation of demand with respect to costs of supplying trans-

$$\text{port } \frac{\partial Q_{ij}}{\partial a_{ij}} = \frac{\partial Q_{ij}}{\partial t_{ij}} \frac{\partial t_{ij}}{\partial a_{ij}} = - \left( \frac{\delta}{\hat{c}_j - t_{ij}} + \frac{2+\delta}{\hat{c}_j - (2+\delta)t_{ij}} \right) Q_{ij} \frac{1}{\varepsilon n^T - 1}.$$

$$\text{Second component: } \frac{\partial Q_{ij}}{\partial a_{ij}} \frac{\mu_{ij}}{n^T} = - \frac{\varepsilon}{t_{ij}} Q_{ij} \frac{\varepsilon n^T}{\varepsilon n^T - 1} \frac{\mu_{ij}}{n^T} = - \varepsilon \frac{1}{\varepsilon n^T - 1} \frac{Q_{ij}}{n^T} < 0$$

The effect of *decreasing* marginal costs  $a_{ij}$  on variable profits  $\pi_{ij}^{var}$  in the transport sector is therefore positive, if the demand elasticity exceeds one  $\epsilon > 1$ .

$$\frac{\partial \pi_{ij}^{var}}{\partial a_{ij}} = \left[ \frac{1 - \epsilon}{\epsilon n^T - 1} \right] \frac{Q_{ij}}{n^T} < 1 \quad \text{if } \epsilon > 1 \quad (\text{A2})$$

## A.2 | AN OLIGOPOLISTIC LOGISTICS SECTOR WITH A COMPETITIVE FRINGE

If a competitive fringe is active in the market, decisions of oligopolistic firms are affected by the presence of the fringe firms. We model the competitive fringe as firms being price takers adjusting output. Suppose their supply function as a group is given by  $Q_f = dQ = (1 - t^{-\alpha})Q$ , where  $d$  denotes the market share of the fringe firms,  $t > 1$  is the price of the transport service and  $\alpha > 0$  is a parameter. The market share increases according to  $t$ . The oligopolistic firms take this into account when maximising profits. Suppose that demand is iso-elastic and given by  $Q = At^{-\epsilon}$ . Demand served by oligopolistic firms is  $(1-d)Q = At^{-(\epsilon+\alpha)}$ . Each of the symmetric firm earns  $1/n$  of the remaining market, where  $n$  is the number of oligopolists. Profit maximisation yields

$$\frac{\partial \pi}{\partial t_{ij}} = \frac{Q_{ij}}{n^T} + (t_{ij} - a_{ij}) \frac{\partial Q_{ij}}{\partial t_{ij}} = 0 \quad \rightarrow \quad 1/n^T - (\epsilon + \alpha) = -\frac{a_{ij}}{t_{ij}}(\epsilon + \alpha).$$

Thus, the optimal price is given by

$$t_{ij} = a_{ij} \frac{n^T(\epsilon + \alpha)}{n^T(\epsilon + \alpha) - 1}, \quad (\text{A3})$$

which is very close to the optimal price without a competitive fringe,  $\alpha = 0$ , in (12). Moreover, mark-ups are smaller the more the fringe reacts to price changes.

In the empirical analysis, there is no information about the fringe available. We cannot approximate  $\alpha$  which might cause problems if it differs strongly on the different routes. Hummels et al. (2009) show how important the differences in market structure is. Since only route fixed effects can control for the differences in competition on the different routes, we state this as a possible source of an omitted variable bias.

## APPENDIX B

## B.1 | ROBUSTNESS OF THE SIMULATION RESULTS

TABLE B1 Small changes in variable costs: The discrete investment case

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
	Omitting	Proxy	Proxy	Proxy	Investm.	IV
	$I_{ij}^d$	Top 150	Top 250	Top 350	$I_{ij}^d$	Exports <sub>ij</sub>
Dependent variable: Bilateral transport costs $t_{ij}$						
$dist_{ij}$	0.281 (0.010)	0.223 (0.006)	0.208 (0.005)	0.209 (0.006)	0.196 (0.002)	0.166 (0.007)
$cap-gdp_i$	1.654 (0.049)	1.230 (0.032)	1.093 (0.025)	1.086 (0.028)	0.966 (0.013)	0.717 (0.055)
$prod-tr_i$	-1.353 (0.045)	-1.122 (0.029)	-1.040 (0.024)	-1.026 (0.027)	-0.982 (0.007)	-0.672 (0.043)
Inv. proxy		-0.658 (0.009)	-0.605 (0.010)	-0.497 (0.012)	-1.03 (0.005)	-0.125 (0.007)
$R^2$	0.59	0.77	0.82	0.78	0.92	0.70

Note: Standard errors in parentheses. Estimations include unreported year dummies. Simulations differ from those reported in Table 2 by assuming a low-variable-cost technology which halves variable costs ( $I = 2$ ) instead of reducing it to a third. Moreover, they are based on only 1000 repetitions.

Source: Generic data. Own calculations.

TABLE B2 Small changes in variable costs: The continuous investment case

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
	Omitting	Proxy	Proxy	Proxy	Investm.	IV
	$I_{ij}^c$	Top 150	Top 250	Top 350	$I_{ij}^c$	Exports <sub>ij</sub>
Dependent variable: Bilateral transport costs $t_{ij}$						
$dist_{ij}$	0.273 (0.005)	0.245 (0.004)	0.237 (0.004)	0.231 (0.004)	0.193 (0.002)	0.198 (0.004)
$cap-gdp_i$	1.545 (0.029)	1.338 (0.023)	1.266 (0.022)	1.122 (0.021)	0.946 (0.014)	0.928 (0.032)
$prod-tr_i$	-1.351 (0.028)	-1.249 (0.023)	-1.195 (0.021)	-1.162 (0.020)	-0.965 (0.013)	-0.901 (0.025)
Inv. proxy		-0.321 (0.009)	-0.301 (0.007)	-0.287 (0.006)	-1.100 (0.012)	-0.084 (0.004)
$R^2$	0.75	0.81	0.83	0.84	0.88	0.85

Note: Standard errors in parentheses. Estimations include unreported year dummies. Simulations differ from those reported in Table 3 by assuming a low-variable-cost technology which halves variable costs ( $I_c = (1 + ex_{ij}/4500)^{0.35}$ ) instead of reducing it to a third. Moreover, they are based on only 1000 repetitions.

Source: Generic data. Own calculations.

TABLE B3 Large changes in variable costs: The discrete investment case

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
	Omitting	Proxy	Proxy	Proxy	Investm.	IV
	$I_{ij}^d$	Top 150	Top 250	Top 350	$I_{ij}^d$	Exports <sub>ij</sub>
Dependent variable: Bilateral transport costs $t_{ij}$						
$dist_{ij}$	0.362 (0.019)	0.253 (0.011)	0.226 (0.009)	0.229 (0.011)	0.196 (0.002)	0.137 (0.013)
$cap-gdp_i$	2.309 (0.094)	1.506 (0.060)	1.253 (0.046)	1.260 (0.052)	0.966 (0.012)	0.452 (0.099)
$prod-tr_i$	-1.708 (0.086)	-1.271 (0.054)	-1.118 (0.042)	-1.104 (0.049)	-0.982 (0.012)	-0.383 (0.076)
Inv. proxy		-1.242 (0.017)	-1.135 (0.020)	-0.915 (0.024)	-1.025 (0.003)	-0.237 (0.011)
$R^2$	0.44	0.72	0.77	0.71	0.96	0.59

Note: Standard errors in parentheses. Estimations include unreported year dummies.

Simulations differ from those reported in Table 2 by assuming a low-variable-cost technology which reduces variable costs to a quarter ( $I = 4$ ) instead of reducing it to a third as in the benchmark. Moreover, they are based on only 1000 repetitions.

Source: Generic data. Own calculations.

TABLE B4 Large changes in variable costs: The continuous investment case

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
	Omitting	Proxy	Proxy	Proxy	Investm.	IV
	$I_{ij}^c$	Top 150	Top 250	Top 350	$I_{ij}^c$	Exports <sub>ij</sub>
Dependent variable: Bilateral transport costs $t_{ij}$						
$dist_{ij}$	0.361 (0.009)	0.320 (0.008)	0.305 (0.007)	0.294 (0.007)	0.192 (0.002)	0.233 (0.006)
$cap-gdp_i$	2.223 (0.053)	1.924 (0.047)	1.794 (0.044)	1.696 (0.041)	0.935 (0.014)	1.083 (0.044)
$prod-tr_i$	-1.838 (0.052)	-1.675 (0.046)	-1.597 (0.043)	-1.534 (0.040)	-0.956 (0.013)	-1.035 (0.034)
Inv. proxy		-0.465 (0.013)	-0.461 (0.011)	-0.459 (0.010)	-1.052 (0.006)	-0.157 (0.005)
$R^2$	0.69	0.75	0.78	0.80	0.94	0.84

Note: Standard errors in parentheses. Estimations include unreported year dummies.

Simulations differ from those reported in Table 3 by assuming a low-variable cost technology which reduces variable costs to a quarter ( $I_c = (1 + ex_{ij}/700)^{0.35}$ ) instead of reducing it to a third as in the benchmark. Moreover, they are based on only 1000 repetitions.

Source: Generic data. Own calculations.

## APPENDIX C

## C.1 | DESCRIPTIVE STATISTICS

TABLE C1 Descriptive statistics: Generic data set

Variable	Mean	Std. dev.	Min	Max
$GDP_i$	5221.0	1607.4	2515.4	8768.3
$GDP_j$	5223.2	1626.3	2378.2	9112.6
$dist_{ij}$	4917.4	2387.8	124.8	11672.7
$gdp-cap_i$	1.94	0.23	1.52	2.37
$I_{ij}$ (discrete)	1.13	0.49	1	3
$I_{ij}$ (continuous)	1.30	0.29	1.0	2.75
$t_{ij}$ (discrete indicator)	0.99	0.30	0.12	1.97
$t_{ij}$ (cont. indicator)	0.84	0.31	0.16	1.97
Exports $_{ij}$ (discrete indicator)	3502.4	7390.3	.0005	59,339
Exports $_{ij}$ (cont. indicator)	4789.4	6562.9	.0005	55,933

Source: Generic data. Own calculations.

TABLE C2 Descriptive statistics: Empirical data set

Variable	Obs.	Mean	Std. dev.	Min	Max
$t_{ij}$	7072	408.54	195.38	53.77	1100.83
$dist_{ij}$	7200	6444.82	5041.81	59.62	19629.5
$gdp-cap_i$	7200	43250.58	22369.22	9271.40	111062.3
$prod-tr_i$	7140	76.78993	30.62209	27.01311	163.1495
Top 150	7200	0.083	0.2764046	0	1
Top 250	7200	0.139	0.346	0	1
Top 350	7200	0.194	0.396	0	1
Exports $_{ij}$ (in Tsd. US\$)	7192	4,797,815	1.75e+07	0.022	3.54e+08
$GDP_i$ (in Mrd. US\$)	7200	1607.98	3079.24	13.68	18318.7
$GDP_j$ (in Mrd. US\$)	7140	1141.86	2501.33	13.68	18318.7

Source: Dataset of transport prices (UPS, 2020), geodesic distances (CEPII, 2020), bilateral export data (OECD, 2021d), GDP data (World Bank, 2020) and labour productivity (OECD, 2021b, 2021c). Own calculation.

TABLE C3 Price correlation for 10 kg packages

Transport firm	UPS	DHL	FedEx
UPS	1		
DHL	0.99	1	
FedEx	0.99	0.99	1
UPS	Express (Ex)		Express (Im)
Express Saver (Ex)	0.8628	Express Saver (Im)	1

Source: Data from companies' websites. Own calculations.

TABLE C4 Prices and distances in German trade

Partner	Price	Distance	Rank	Distance	Rank	Sea-way	Rank
Country	Zone	Frankfurt	(of 60)	Berlin	(of 60)	Hamburg	(of 54)
Algeria	12	1659	25	1929	28	3697	17
Argentina	11	11,512	57	11,910	57	12,164	38
Australia	10	16,563	59	16,094	59	21,790	53
Austria	2	764	9	524	4	-	
Belgium	2	197	2	651	8	640	2
Brazil	10	9848	50	10,177	53	10,469	34
Bulgaria	42	1572	23	1319	22	6443	25
Canada	7	6161	37	6476	38	17,009	46
Chile	11	12,098	58	12,109	58	14,549	41
China	9	7785	39	7353	39	19,628	50
Colombia	11	9063	43	9431	46	9096	31
Costa Rica	11	9222	46	9633	49	9777	33
Croatia	41	912	12	769	12	5874	22
Czech Rep.	41	546	7	280	1	-	
Denmark	2	596	8	355	2	847	5
Egypt	11	3112	32	2892	32	6552	26
Estonia	42	1421	20	1041	18	1760	10
Finland	4	1475	21	1105	19	1803	11
France	2	440	4	878	16	4210	18
Greece	4	1991	27	1804	26	5669	21
Hong Kong	9	9210	45	8751	43	18,302	49
Hungary	41	976	16	688	10	-	
India	9	6229	38	6291	36	12,063	36
Indonesia	10	11,227	55	10,782	54	16,178	45
Iceland	6	2189	30	2388	30	2237	13
Ireland	4	921	13	1318	21	1569	9
Israel	11	3123	33	2900	33	6640	27
Italy	3	1146	18	1184	20	4502	20
Ivory Coast	12	5237	35	5483	35	7226	28
Japan	9	9298	47	8918	44	21,032	52
Lithuania	42	1273	19	818	14	1408	7
Luxembourg	2	216	3	603	7	-	
Malaysia	10	10,070	51	9615	47	15,359	43
Mexico	8	9400	48	9727	50	12,801	39
Morocco	12	2237	31	2690	31	2993	15
Netherlands	2	174	1	577	6	423	1
Nigeria	11	5021	34	5204	34	8060	29
Norway	5	969	15	838	15	783	4
New Zealand	11	18,825	60	17,747	60	24,544	54
Panama	11	8996	42	9415	45	9653	32



TABLE C4 (Continued)

Partner	Price	Distance	Rank	Distance	Rank	Sea-way	Rank
Country	Zone	Frankfurt	(of 60)	Berlin	(of 60)	Hamburg	(of 54)
Peru	11	10,660	54	11,099	55	12,133	37
Philippines	10	10,320	52	9867	51	18,095	48
Poland	41	966	14	516	3	1282	6
Portugal	4	1892	26	2314	29	2499	14
Russia	6	2065	29	1608	23	2065	12
Singapore	9	10,380	53	9923	52	15,700	44
Slovakia	41	817	11	553	5	-	
Slovenia	41	815	10	724	11	5941	23
Spain	4	1479	22	1870	27	3642	16
Sweden	4	1119	17	810	13	1541	8
Switzerland	5	504	6	671	9	-	
Thailand	9	9066	44	8603	42	17,173	47
Tunisia	12	1649	24	1766	25	4368	19
Turkey	6	2038	28	1737	24	6236	24
UK	3	495	5	932	17	754	3
USA	7	6035	36	6385	37	14,989	42
Uruguay	11	11,412	56	11,817	56	11,962	35
Venezuela	11	7985	40	8430	41	8530	30

Note: Prices 2019: Zone 2: 142.00 €, Zone 3: 214.95 €, Zone 4: 237.40 €, Zone 41: 305.50 €, Zone 42: 308.55 €, Zone 5: 214.95 €, Zone 6: 331.45 €, Zone 7: 267.20 €, Zone 8: 313.90 €, Zone 9: 435.80 €, Zone 10: 564.60 €, Zone 11: 615.40 €, Zone 12: 728.90 €.

Source: Dataset of transport prices–UPS (2020), Geodesic distances – CEPII (2020), Maritime distances–[www.searates.com](http://www.searates.com). Own calculation.

TABLE C5 UPS Price differences within country pairs, 2019

<b>(a) Prices of exports and imports offered in the same country</b>			
	By more than 20%	By more than 30%	No. of routes
Export price smaller than import price	270	133	1753
Import prices smaller than export price	431	266	1753
Total price deviations	701	399	1753
in %	40.0	22.8	
	Mean	Maximum	Route
$ \text{export}_{ij} - \text{import}_{ij}  / \text{export}_{ij}$	0.236	1.62	Canada–Israel
<b>(b) Prices of exports and imports offered in different countries of the pair: <math>\text{export}_{ij} = \text{import}_{ji}</math>, both in US\$</b>			
	Mean	Maximum	Route
$ \text{export}_{ij} - \text{import}_{ji}  / \text{export}_{ij}$	0.282	2.16	Israel–USA

Note: The price difference ( $\text{export}_{i, \text{USA}} - \text{import}_{\text{USA}, i}$ ) is always negative.

The price difference ( $\text{export}_{i, \text{UK}} - \text{import}_{\text{UK}, i}$ ) is almost always positive.

Source: Data from UPS' websites, exchange rates from OECD (2021a). Own calculations.

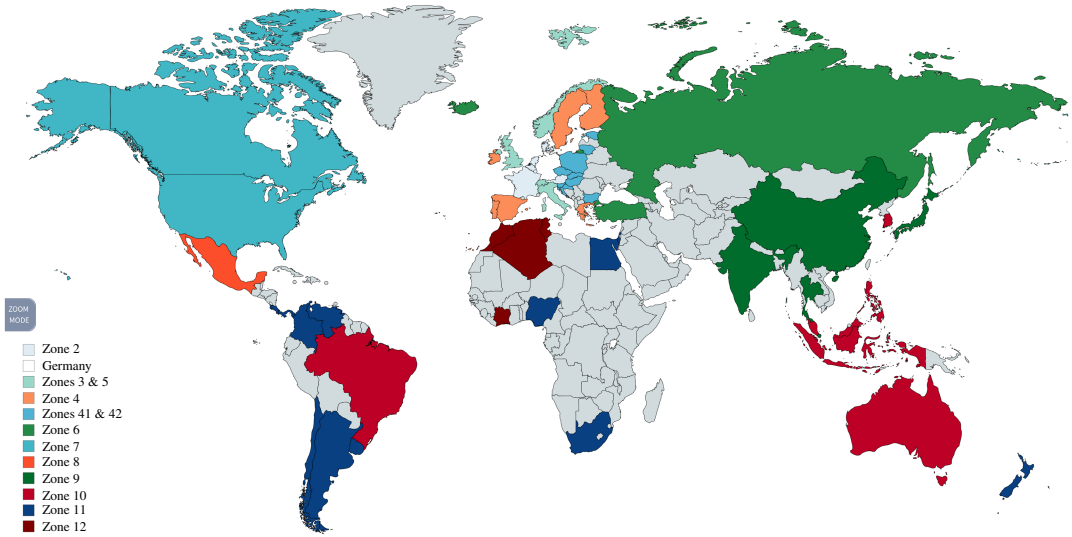


FIGURE C1 UPS transport prices for German exports (2019).

Source: <https://mapchart.net/world.html>, own representation. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

## APPENDIX D

## D.1 | ROBUSTNESS OF THE EMPIRICAL RESULTS

TABLE D1 Time-varying fixed effects

	(i)	(ii)	(iii)	(iv)	(v)
	Omitting	Proxy	Proxy	Proxy	IV
	$I_{ij}$	Top 150	Top 250	Top 350	Exports $_{ij}$
Dependent variable: Bilateral transport costs $t_{ij}$ (in logs)					
$dist_{ij}$	0.2339*** (0.0085)	0.2197*** (0.0087)	0.2188*** (0.0086)	0.2236*** (0.0090)	0.2345*** (0.0085)
Top 150		-0.1241*** (0.0210)			
Top 250			-0.0920*** (0.0173)		
Top 350				-0.0524*** (0.0156)	
Exports $_{ij}$					-0.0659*** (0.0081)
No. of obs.	7072	7072	7072	7072	7013
$R^2$	0.902	0.904	0.904	0.902	0.901
Endog. test					36.125
$p$ -val.					0
Overid. test					56.126
$p$ -val.					0
Underid. test					5242.305
$p$ -val.					0
Weak id. test					1.0E+04
$p$ -val.					0

Note: The single equation estimations are reported with cluster-robust standard errors in parentheses with significance at the \*\*\* $p < .01$ , \*\* $p < .05$ , \* $p < .1$  level. Estimations include unreported constant terms and time-varying (reporting and receiving) country dummies.

Source: Dataset of transport prices (UPS, 2020), geodesic distances (CEPII, 2020), bilateral export data (OECD, 2021d), GDP data (World Bank, 2020) and labour productivity (OECD, 2021b, 2021c). Own calculation.

TABLE D 2 Trade data specifications

	Large sample					Small sample				
	(ii)	(iii)	(iv)	(v)	(v)	(ii)	(iii)	(iv)	(v)	(v)
Proxy	Proxy	Proxy	Proxy	IV	IV	Proxy	Proxy	Proxy	Proxy	IV
Top 150	Top 250	Top 350	Top 350	Exports <sub>ij</sub>	Exports <sub>ij</sub>	Top 150	Top 250	Top 350	Top 350	Exports <sub>ij</sub>
Dependent variable: $t_{ij}$										
$dist_{ij}$	0.1645*** (0.0084)	0.1613*** (0.0084)	0.1586*** (0.0087)	0.1296*** (0.0054)	0.1652*** (0.0085)	0.1612*** (0.0085)	0.1586*** (0.0087)	0.1391*** (0.0052)	0.1391*** (0.0052)	0.1391*** (0.0052)
$gdp-cap_i$	0.1414*** (0.0367)	0.1496*** (0.0370)	0.1426*** (0.0371)	0.1735*** (0.0264)	0.1387*** (0.0368)	0.1426*** (0.0369)	0.1352*** (0.0371)	0.1084*** (0.0216)	0.1084*** (0.0216)	0.1084*** (0.0216)
$prod-tr_i$	-0.1044** (0.0429)	-0.1137*** (0.0427)	-0.1057** (0.0428)	-0.1153*** (0.0323)	-0.0999** (0.0428)	-0.1039** (0.0426)	-0.0967** (0.0430)	-0.0583*** (0.0275)	-0.0583*** (0.0275)	-0.0583*** (0.0275)
Top 150	-0.3491*** (0.0292)				-0.3353*** (0.0284)					
Top 250		-0.2875*** (0.0256)				-0.2876*** (0.0244)				
Top 350			-0.2473*** (0.0230)				-0.2343*** (0.0227)			
Exports <sub>ij</sub>				-0.0761*** (0.0037)						-0.0591*** (0.0030)
No. of obs.	7012	7012	7012	5789	7012	7012	7012	7012	6931	6931
$R^2$	0.304	0.306	0.304	0.343	0.302	0.306	0.301	0.312	0.312	0.312
Endog. test				19.423				34.01	34.01	34.01
$p$ -val.				0				0	0	0
Overid. test				10.046				60.441	60.441	60.441

TABLE D 2 (Continued)

	Large sample			Small sample			
	(ii) Proxy Top 150	(iii) Proxy Top 250	(iv) Proxy Top 350	(ii) Proxy Top 150	(iii) Proxy Top 250	(iv) Proxy Top 350	
<i>p</i> -val.							
Underid. test							
<i>p</i> -val.							
Weak id. test							
<i>p</i> -val.							
		(v) IV Exports <sub><i>ij</i></sub>		(ii) Proxy Top 150	(iii) Proxy Top 250	(iv) Proxy Top 350	(v) IV Exports <sub><i>ij</i></sub>
		0					0
		4073.031					5029.211
		0					0
		6859.715					9152.49
		0					0

Note: Cluster-robust standard errors in parentheses with significance at the \*\*\**p* < .01, \*\**p* < .05, \**p* < .1 level. Estimations include unreported constant terms and time dummies.

Source: Dataset of transport prices (UPS, 2020), geodesic distances (CEPII, 2020), bilateral export data (OECD, 2021d), GDP data (World Bank, 2020) and labour productivity (OECD, 2021b, 2021c). Own calculation.

TABLE D3 Extra-EU trade by transportation mode

	<u>Air</u>	<u>Air</u>	<u>Air</u>	<u>Total</u>	<u>Total</u>
	<u>(i)</u>	<u>(ii)</u>	<u>(iii)</u>	<u>(iv)</u>	<u>(v)</u>
	<u>Proxy</u>	<u>Proxy</u>	<u>IV</u>	<u>Proxy</u>	<u>IV</u>
	<u>Top 150</u>	<u>Top 250</u>	<u>Exports<sub>ij</sub></u>	<u>Top 150</u>	<u>Exports<sub>ij</sub></u>
Dependent variable: $t_{ij}$					
$dist_{ij}$	0.1168*** (0.0123)	0.1231*** (0.0123)	0.1157*** (0.0095)	0.1168*** (0.0123)	0.0663*** (0.0077)
$gdp-cap_i$	-0.049 (0.0388)	-0.0672* (0.0394)	-0.1320*** (0.0324)	-0.049 (0.0388)	-0.1738*** (0.0299)
$prod-tr_i$	0.028 (0.0496)	0.070 (0.0510)	0.2421*** (0.0421)	0.028 (0.0496)	0.1974*** (0.0376)
Top 150	-0.2502*** (0.0334)			-0.2502*** (0.0334)	
Top 250		-0.2240*** (0.0284)			
Exports <sub>ij</sub>			-0.0977*** (0.0051)		-0.0804*** (0.0042)
No. of obs.	3187	3187	2807	3187	3149
$R^2$	0.363	0.366	0.332	0.363	0.386
Endog. test			163.402		57.067
$p$ -val.			0		0
Overid. test			5.648		28.898
$p$ -val.			0.02		0
Underid. test			1252.246		2408.05
$p$ -val.			0		0
Weak id. test			1126.796		5102.42
$p$ -val.			0		0

Note: Cluster-robust standard errors in parentheses with significance at the \*\*\* $p < .01$ , \*\* $p < 0.05$ , \* $p < 0.1$  level. Estimations include unreported constant terms and time dummies.

Source: Dataset of transport prices (UPS, 2020), geodesic distances (CEPII, 2020), bilateral export data (EUROSTAT, 2022, OECD, 2021d), GDP data (World Bank, 2020) and labour productivity (OECD, 2021b, 2021c). Own calculation.

TABLE D4 Trade imbalances

	(i)	(ii)	(iii)	(iv)	(v)
	Omitting	Proxy	Proxy	Proxy	IV
	$I_{ij}$	top 150	top 250	top 350	Exports $_{ij}$
Dependent variable: $t_{ij}$					
$dist_{ij}$	0.1803*** (0.0093)	0.1647*** (0.0089)	0.1636*** (0.0089)	0.1601*** (0.0091)	0.1524*** (0.0052)
$gdp-cap_i$	0.1075*** (0.0372)	0.1193*** (0.0372)	0.1244*** (0.0372)	0.1187*** (0.0374)	0.0761** (0.0217)
$prod-tr_i$	-0.071 (0.0442)	-0.0737* (0.0433)	-0.0806* (0.0430)	-0.0761* (0.0431)	-0.030 (0.0275)
Top 150		-0.3323*** (0.0295)			
Top 250			-0.2766*** (0.0255)		
Top 350				-0.2448*** (0.0232)	
Exports $_{ij}$					-0.0526*** (0.0029)
$trade_{ij}$	0.2043*** (0.0387)	0.1812*** (0.0374)	0.1658*** (0.0377)	0.1532*** (0.0375)	0.01063*** (0.0029)
$trade_{ij} \times d_{trade}$	-0.2315*** (0.0645)	-0.1730*** (0.0630)	-0.1422** (0.0633)	-0.1141* (0.0632)	-0.056 (0.0455)
No. of obs.	7005	7005	7005	7005	6946
$R^2$	0.281	0.310	0.312	0.312	0.322
Endog. test					0.753
$p$ -val.					0.3855
Overid. test					74.605
$p$ -val.					0
Underid. test					5497.373
$p$ -val.					0
Weak id. test					1.30E+0.4
$p$ -val.					0

Note: Cluster-robust standard errors in parentheses with significance at the \*\*\* $p < .01$ , \*\* $p < .05$ , \* $p < .1$  level. Estimations include unreported constant terms and time dummies.

Source: Dataset of transport prices (UPS, 2020), geodesic distances (CEPII, 2020), bilateral export data (OECD, 2021d), GDP data (World Bank, 2020) and labour productivity (OECD, 2021b, 2021c). Own calculation.