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Airplanes and comparative advantage ☆

James Harrigan

Department of Economics, University of Virginia, P.O. Box 400182, Charlottesville VA 22904-4182, United States

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ABSTRACT

Airplanes are a fast but expensive means of shipping goods, a fact which has implications for comparative advantage. The paper develops a Ricardian model with a continuum of goods which vary by weight and hence transport cost. Comparative advantage depends on relative air and surface transport costs across countries and goods, as well as stochastic productivity. A key testable implication is that the U.S. should import heavier goods from nearby countries, and lighter goods from faraway counties. This implication is tested using detailed data on U.S. imports from 1990 to 2003. Looking across goods the U.S. imports, nearby exporters have lower market share in goods that the rest of the world ships by air. Looking across exporters for individual goods, distance from the US is associated with much higher import unit values. These effects are large, which establish that the model identifies an important influence on specialization and trade.

1. Introduction

Countries vary in their distances from each other, and traded goods have differing physical characteristics. As a consequence, the cost of shipping goods varies dramatically by type of good and how far they are shipped. A moment's reflection suggests that these facts are probably important for understanding international trade, yet they have been widely ignored by trade economists. In this paper I focus on one aspect of this set of facts, which is that airplanes are a fast but expensive means of shipping goods.

The fact that airplanes are fast and expensive means that they will be used for shipping only when timely delivery is valuable enough to outweigh the premium that must be paid for air shipment. They will also be used disproportionately for goods that are produced far from where they are sold, since the speed advantage of airplanes over surface transport is increasing in distance. In this paper I show how these considerations can be incorporated into the influential Eaton and Kortum (2002) model of comparative advantage. In this general model, differences across goods in transport costs (both air and surface) and the value that consumers place on timely delivery interact with relative distance to affect global trade patterns.

The model of the paper delivers two empirical implications that I test using highly disaggregated data on all U.S. imports from 1990 to 2003. The first implication is that nearby trading partners (Canada and Mexico) should have lower market shares in goods that more distant trading partners ship primarily by air. The second implication is that goods imported from more distant locations will have higher unit values. Both of these implications are resoundingly confirmed, and the size of the effects is economically important. In short, I find that the relative distance and relative transport cost effects emphasized in the model are an important influence on U.S. trade. Finally, I show that air shipment is much more likely for goods that have a high value/weight ratio.

There is a small, recent literature that looks at some of the issues that I analyze in this paper. The most direct antecedents of my paper are Eaton and Kortum (2002) and Hummels and Skiba (2004). Limao and Venables (2002) is a theory paper that models the interaction between specialization and trade costs, illustrating how the equilibrium pattern of specialization involves a tradeoff between comparative production costs and comparative transport costs. The geographical structure has a central location that exports a numeraire good and imports two other goods from more remote locations. These more remote locations have a standard 2×2 production structure, and when endowments are the same at all locations and transport costs are the same for both goods the model reduces to one where greater distance from the center has simple effects on aggregate welfare: more distant countries are poorer because they face higher transport costs. When endowments and transport costs differ the analysis becomes more nuanced, with relative transport costs interacting with relative endowments to determine welfare and comparative advantage (for example, a relatively centrally located country that is abundant in the factor used intensively in the low trade cost good will have high trade volumes and high real GDP, while countries that are more distant, and/or that are abundant in the factor used intensively in the high transport cost good, will have lower trade volumes and real GDP). This rich theoretical framework is not evaluated

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E-mail address: james.harrigan@virginia.edu.

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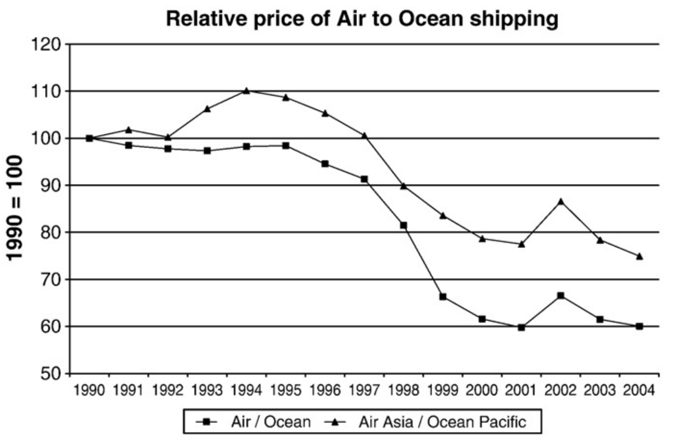


Chart 1. Notes to Chart 1: data are price indices for U.S. imports of air freight and ocean liner shipping services from the Bureau of Labor Statistics, http://www.bls.gov/mxp. The "Air/Ocean" series divides all US imports of air freight services by all imports of ocean liner services, while the "Air Asia/Ocean Pacific" series divides the index for air freight imports from Asia by the index for ocean liner imports from the Pacific region.

empirically in the paper, nor to my knowledge has it been taken to the data in subsequent work.

In contrast to Limao and Venables (2002), the paper by Hummels and Skiba (2004) is mainly empirical. Like Limao–Venables the focus is on the implications of differences in transport costs across goods on trade patterns, but unlike Limao-Venables (and virtually all of trade theory) they challenge the convenient assumption that transport costs take the iceberg form. Hummels–Skiba show that actual transport costs are much closer to being per unit than iceberg, and they use simple price theory to show the implications for trade: imports from more distant locations will have disproportionately higher f.o.b. prices. This implication is strongly confirmed using a large dataset on bilateral product-level trade. As the model of the paper is partial equilibrium, Hummels–Skiba do not address the equilibrium location of production.

A key theoretical motivation to my analysis below is Deardorff (2004). Deardorff works with a series of simple models to make a profound point about trade theory in a world of transport costs: "local comparative advantage" (defined as autarky prices in comparison to nearby countries rather than the world as a whole) is what matters in determining trade in a world with trade costs. I embed this insight into the Eaton and Kortum (2002) model of Ricardian comparative advantage in what follows.

A related literature is the "new economic geography", which is well-summarized in Fujita et al. (1999) and Baldwin et al. (2003). In new economic geography models, the interaction between increasing returns and transport costs are a force for agglomeration, and through this channel trade costs influence trade patterns. The mechanism in these models is quite different from the comparative advantage mechanism in Limao and Venables (2002) and Eaton and Kortum (2002).

David Hummels has written a series of important empirical papers that directly motivated this paper. Hummels (1999) shows that ocean freight rates have not fallen on average since World War 2, and have often risen for substantial periods. By contrast, the cost of air shipment has fallen dramatically. Chart 1 shows that these trends have continued since 1990, with the relative price of air shipping falling 40% between 1990 and 2004. Hummels (2001a) shows that shippers are willing to pay a large premium for faster delivery, a premium that has little to do with the interest cost of goods in transit.[1] Hummels (2001b) analyzes the geographical determinants of trade costs, and decomposes the negative effect of distance on trade into measured and unmeasured costs.

The following section illustrates some key features of U.S. imports by product, trading partner, and transport mode from 1990 to 2003. Section 3 presents the theory, which is then formally tested in Section 4.

2. Airplanes and U.S. imports: a first look

The import data used in this paper are collected by the U.S. Customs Service and reported on CD-ROM. For each year from 1990 to 2003, the raw data include information on the value, quantity (usually number or kilograms), and weight (usually in kilograms) of U.S. imports from all sources. The data also include information on tariffs, transport mode and transport fees, including total transport charges broken down by air, vessel and (implicitly) other, plus the quantity of imports that come in by air, sea, and (implicitly) land.[2] The import data are reported at the 10-digit Harmonized System (HS) level, which is extremely detailed, with over 14,000 codes in 2003.

I aggregate the 10-digit import data for analysis in various ways. For most of the descriptive charts and tables, I work with a broad aggregation scheme that updates Leamer's (1984) classification, which is reported in Table 1. Countries are aggregated by distance and by region, as described in Appendix Table A1 . Distance from the United States is measured in kilometers from Chicago to the capital city of each country.[3]

Table 1 illustrates the great heterogeneity in the prevalence of air freight for U.S. imports, as well as some important changes over the sample. Many products come entirely or nearly entirely by surface transport (oil, iron and steel, and road vehicles) while others come primarily by air (computers, telecommunications equipment, cameras, and medicine). Scanning the list of products and their associated air shipment shares hints at the importance of value to weight and the demand for timely delivery in determining shipment mode. Charts 2 and 3 illustrate the variation in air freight across regions and goods (the regional aggregates are defined in Appendix Table A1).[4] Chart 2 shows that about a quarter of US (non-oil) imports arrived by air in 2003, up from 20% in 1990 (for brevity, in what follows I'll call the proportion of imports that arrive by air "air share"). Excluding NAFTA, the non-oil air share was 35% in 2003. Chart 3 shows that this average conceals great regional variation, which is related to distance: essentially no imports come by air from Mexico and Canada, while Europe's air share is almost half by 2003, up from under 40% in 1990. East Asia's air share increased by about half from over the sample, from 20 to 30%.

3. Airplanes and trade: theory

The data reviewed in the previous section clearly suggest the influence of distance and transport costs on the pattern of trade. In this section I develop a model than can be used to analyze the effects of transport costs on comparative advantage.

My basic framework comes from Eaton and Kortum (2002), simplified in some dimensions and made more complex in others. On the demand side, consumers value timely delivery, and this valuation can differ across goods. On the supply side, timely delivery can be assured in two ways: by surface transport from nearby suppliers, or by air transport from faraway suppliers. Since air transport is expensive, it will only be used by distant suppliers, and

[1] By "the interest cost of goods in transit", I mean the financial cost of having goods in transit before they can be sold. This opportunity cost equals the value of the good × daily interest rate × days in transit.

[2] "Other" transport modes include truck and rail, and are used exclusively on imports from Mexico and Canada.

[3] A convenient source for the distance data is http://www.macalester.edu/~robertson/index.html.

[4] The online Appendix includes additional tables and charts which show variation by product group. The product aggregates correspond to the headings in Table 1.

Table 1
Imports by product and percent air shipped, 1990 and 2003.

Share of total 1990	Share of total 2003	Category	SITC	% of category 1990	Imports by air, % of total 1990	% of category 2003	Imports by air, % of total 2003	SITC description
12.2	8.9	Petroleum						
			33	100.0	2.4	100.0	2.9	Petroleum, petroleum products and related materials
2.2	3.3	Other fuel and raw materials						
			28	35.0	9.1	7.5	13.6	Metalliferous ores and metal scrap
			34	30.6	1.4	74.3	7.6	Gas, natural and manufactured
			23	11.2	6.8	4.5	10.0	Crude rubber
			27	10.6	19.4	5.7	19.6	Crude fertilizers and crude minerals
			26	5.5	7.7	1.6	29.1	Textile fibres
			35	4.3	0.0	3.4	0.0	Electric current
			32	2.7	1.7	2.9	0.3	Coal, coke and briquettes
3.4	2.8	Forest products						
			64	51.2	23.8	43.5	19.5	Paper, paperboard and articles thereof
			24	18.9	4.9	21.2	4.0	Cork and wood
			25	17.3	12.3	7.6	9.5	Pulp and waste paper
			63	12.6	18.3	27.7	13.0	Cork and wood manufactures (excluding furniture)
5.7	4.7	Animal and vegetable products						
			05	19.8	7.4	19.5	5.8	Vegetables and fruit
			03	18.5	31.2	17.4	26.6	Fish, crustaceans, molluscs and aquatic invertebrates
			11	12.7	4.7	17.9	2.7	Beverages
			07	12.0	6.2	9.0	8.2	Coffee, tea, cocoa, spices, and manufactures thereof
			01	10.5	15.0	7.6	14.7	Meat and meat preparations
			29	4.4	36.8	4.8	40.6	Crude animal and vegetable materials, n.e.s.
			06	4.3	3.0	3.7	3.9	Sugars, sugar preparations and honey
			0	4.3	86.6	2.8	83.8	Live animals other than animals of division 03
			04	3.2	5.6	5.6	4.0	Cereals and cereal preparations
			12	2.3	16.2	2.2	14.1	Tobacco and tobacco manufactures
			42	2.3	3.7	2.3	6.6	Fixed vegetable fats and oils, crude, refined or fractionated
			02	1.7	18.9	1.9	14.2	Dairy products and birds' eggs
			09	1.4	6.9	3.2	7.9	Miscellaneous edible products and preparations
			08	1.2	9.6	1.2	5.2	Feeding stuff for animals (not including unmilled cereals)
			22	0.7	11.8	0.5	10.8	Oil-seeds and oleaginous fruits
			21	0.6	44.2	0.2	61.1	Hides, skins and furskins, raw
			43	0.2	3.1	0.3	10.3	Animal or vegetable fats and oils
			41	0.1	13.4	0.1	18.7	Animal oils and fats
15.3	15.9	Labor intensive manufactures						
			84	33.3	56.5	31.4	47.5	Articles of apparel and clothing accessories
			89	32.9	47.0	32.6	46.4	Miscellaneous manufactured articles, n.e.s.
			85	12.8	46.3	7.7	50.1	Footwear
			66	11.6	28.9	13.7	24.5	Non-metallic mineral manufactures, n.e.s.
			82	6.6	12.8	12.2	12.3	Furniture, and parts thereof
			83	2.9	60.9	2.3	58.2	Travel goods, handbags and similar containers
8.1	7.0	Capital intensive manufactures						
			67	24.5	3.3	14.5	7.1	Iron and steel
			68	23.4	17.0	19.4	25.2	Non-ferrous metals
			69	22.2	24.2	28.5	29.4	Manufactures of metals, n.e.s.
			65	15.8	45.8	19.7	46.3	Textile yarn, fabrics, made-up articles, n.e.s
			62	8.7	14.6	9.7	27.0	Rubber manufactures, n.e.s.
			81	3.1	18.4	6.9	20.0	Prefabricated buildings, lighting and plumbing fixtures
			61	2.2	59.1	1.3	65.3	Leather, leather manufactures, n.e.s., and dressed furskins
45.2	45.0	Machinery						
			78	34.2	14.7	31.1	19.4	Road vehicles (including air-cushion vehicles)
			77	15.0	55.3	14.6	60.9	Electrical machinery, apparatus and appliances, n.e.s., and parts
			75	12.3	73.6	14.5	74.5	Office machines and automatic data-processing machines
			76	9.7	57.6	12.7	74.5	Telecommunications and sound-recording/reproducing apparatus
			74	6.4	31.5	6.8	34.7	General industrial machinery and equipment and parts, n.e.s.

(continued on next page)

Table 1 (*continued*)

Share of total 1990	Share of total 2003		SITC	% of category 1990	Imports by air, % of total 1990	% of category 2003	Imports by air, % of total 2003	SITC description
45.2	45.0	Machinery						
			72	5.9	30.2	3.7	35.7	Machinery specialized for particular industries
			71	5.8	40.1	5.7	43.9	Power-generating machinery and equipment
			79	3.3	42.0	3.6	42.8	Other transport equipment
			88	3.0	68.2	2.1	73.7	Photographic apparatus, optical goods, watches
			87	2.7	64.0	4.2	75.5	Professional, scientific and controlling instruments, n.e.s.
			73	1.7	28.9	1.0	41.4	Metalworking machinery
4.5	8.3	Chemicals						
			51	32.7	23.4	33.5	32.2	Organic chemicals
			52	14.0	11.1	7.1	16.8	Inorganic chemicals
			54	11.7	54.6	31.2	65.0	Medicinal and pharmaceutical products
			59	9.2	10.9	6.7	21.6	Chemical materials and products, n.e.s.
			57	8.9	7.2	7.1	19.5	Plastics in primary forms
			58	8.0	24.2	4.6	27.2	Plastics in non-primary forms
			53	5.9	10.4	2.4	18.4	Dyeing, tanning and colouring materials
			55	5.3	28.3	5.4	22.7	Essential oils and resinoids and perfume; cleanser
			56	4.2	8.7	2.0	6.9	Fertilizers (other than those of group 272)

on goods which have both a high demand for timely delivery and a high value/weight ratio (and thus a relatively small cost premium for air shipment).

I derive two testable empirical implications from the model. The first implication is about the cross-section of imported goods: nearby exporters will have a smaller market share in goods that faraway exporters send by air. The second implication concerns the distribution of unit values for a particular good: faraway exporters will sell goods which on average a higher unit value and thus lower transport costs as a share of value.

3.1. Demand

For many transactions, timely delivery is available for a substantial premium over regular delivery. Why would anybody pay such a premium? Possible answers to this question are analyzed in a few recent papers. Evans and Harrigan (2005) derive the demand for timely delivery by retailers, who benefit from ordering from their suppliers after fickle consumer demand is revealed. Evans and Harrigan show the empirical relevance of this channel using data on the variance of demand and the location of apparel suppliers: for goods where timely delivery is important, apparel suppliers to U.S. retailers are more likely to be located in Mexico, where timely delivery to the U.S. market is cheap, while goods where timeliness is less important are more likely to be located in more distant, lower-wage countries such as China. Harrigan and Venables (2006) focus on the importance of the demand for timeliness as a force for agglomeration. They analyze this question from a number of angles, including a model of the demand for “just in time” delivery. The logic is that more complex production processes are more vulnerable to disruption from faulty or delayed parts, with the result that the demand for timely delivery of intermediate goods is increasing in complexity of final production.

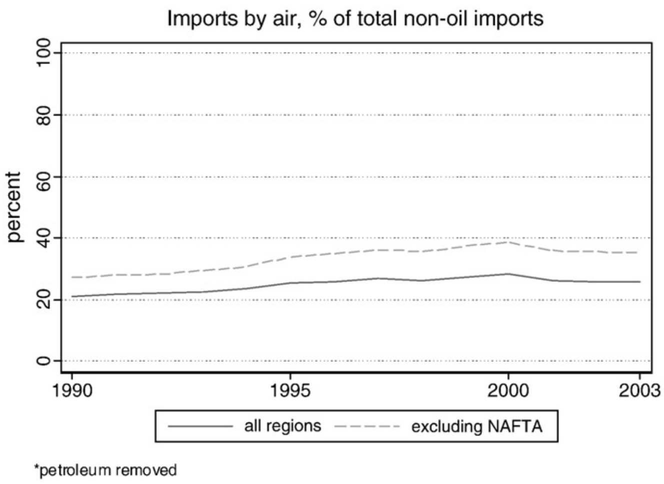


Chart 2.

While the details of demand and supply differ across models, the message of Evans and Harrigan (2005) and Harrigan and Venables (2006) is that it is uncertainty that generates a willingness to pay a premium for timely delivery. For the purposes of the present paper I will model this result with a simple shortcut, and suppose that utility is higher for goods that are delivered quickly. Looking ahead, timely delivery can be assured in one of two ways: by proximity between final consumers and production, or by air shipment when producers are located far from consumers. The determination of the equilibrium location of producers is a central concern of the model.

There is a unit continuum of goods indexed by z, with consumption denoted by $x(z)$. Utility is Cobb–Douglas in consumption, and the extra utility derived from timely or “fast” delivery is $f(z)>1$.[5] Letting F denote the set of goods that are delivered in a timely matter (for brevity I will call these “fast goods”), utility is given by

$$\ln U = \int_{z \in F} \ln[f(z)x(z)]dz + \int_{z \notin F} \ln x(z)dz \tag{1}$$

Order goods so that $F = [0, z'] \subseteq [0,1]$. Then the utility function can be informatively re-written as

$$\ln U = \int_0^{z'} \ln f(z)dz + \int_0^1 \ln x(z)dz$$

For nominal income Y, the resulting demand functions are

$$x(z) = \frac{Y}{p(z)}$$

[5] Eaton and Kortum (2002) assume CES preferences. Since the elasticity is substitution plays no role in the solution of their model or mine, I use Cobb–Douglas preferences for simplicity.

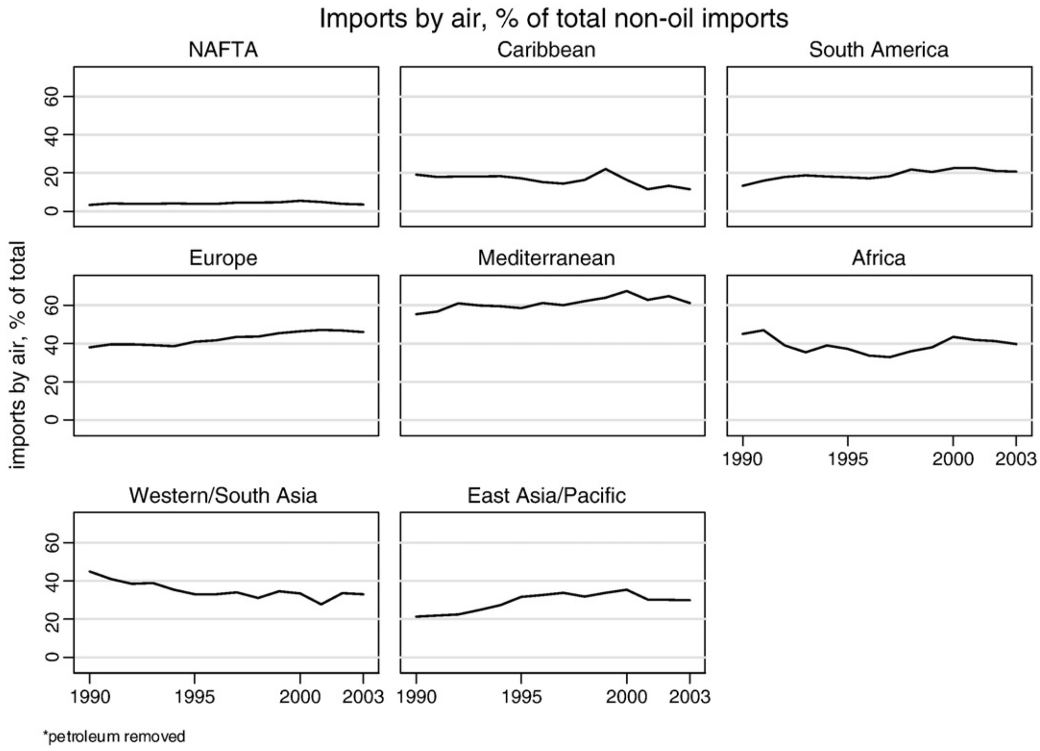


Chart 3.

That is, all goods have the same expenditure share, regardless of whether or not they are fast. Denoting the prices of fast goods with a superscript f, the indirect utility function is

$$\ln V(p,Y) = \int_0^{z'} \ln f(z)dz + \ln Y - \int_0^{z'} \ln p^f(z)dz - \int_{z'}^1 \ln p(z)dz$$

Changing the set of fast goods at the margin has the following effect on utility,

$$\frac{\partial \ln V(p,Y)}{\partial z'} = \ln f\left(z'\right) - \ln p^f\left(z'\right) + \ln p\left(z'\right)$$

which is positive iff

$$f\left(z'\right) > \frac{p^f\left(z'\right)}{p(z')}$$

This inequality implies that consumers will prefer fast delivery of a good if and only if the marginal utility of timeliness exceeds the relative price of fast delivery.

3.2. Supply: shipping mode and geography

Atomistic producers are assumed to be perfectly competitive, which ensures that FOB price equals unit cost, but there is a choice of shipping mode (air or surface) and consequent CIF price paid.[6] Shipping costs are of the iceberg form, so that for one unit to arrive $t(z) \geq 1$ units must be shipped.

I now introduce distance into the model. Denote air and surface iceberg shipping costs from origin country o to destination country d respectively as $a_{od}(z)$ and $s_{od}(z)$, and assume that $a_{od}(z) > s_{od}(z) \geq 1$ $\forall z$: air shipping is never cheaper than surface shipping. If producers are located near consumers, then (by assumption) they can achieve timely delivery using surface shipment. If producers are located far away from consumers, then they must decide if the extra expense of air shipment is worthwhile. The answer is yes if consumer preference for fast delivery $f(z)$ is higher than the relative cost of air shipment, $a_{od}(z) / s_{od}(z)$. Given the structure of costs and demand, the equilibrium shipping mode for producers located far from their customers is

$$t_{od}(z) = s_{od}(z) \quad \text{if} \quad 1 \leq \frac{a_{od}(z)}{s_{od}(z)f(z)}$$
$$t_{od}(z) = a_{od}(z) \quad \text{if} \quad 1 > \frac{a_{od}(z)}{s_{od}(z)f(z)}$$

Now order z so that $\frac{a_{od}(z)}{s_{od}(z)f(z)}$ is monotonically weakly increasing in z, and define $\overline{z}_{od}$ as the implicit solution to[7]

$$\frac{a_{od}(\overline{z}_{od})}{s_{od}(\overline{z}_{od})f(\overline{z}_{od})} = 1 \quad (2)$$

By the ordering of z, $\forall z < \overline{z}_{od}$ the optimal shipping mode is air and for all other goods the optimal mode is surface.

For every bilateral trade route from origin country o to destination country d, there will be a cutoff $\overline{z}_{od}$. This cutoff doesn't depend on wages or technology, only on bilateral transport costs. As is traditional in trade models, I will assume that preferences, including the demand for timeliness schedule $f(z)$, do not vary across countries, so that bilateral variation in transport costs determine which goods are shipped by surface and which by air.

[6] FOB stands for "free on board", and refers to the price of the good before transport costs are added. CIF stands for "cost, insurance, and freight", and refers to the price after transport costs have been added.

[7] For ease of exposition, I make the innocuous assumption that $\overline{z}$ is unique.

3.3. Supply–competition

The supply side of the model is based on Eaton and Kortum (2002), henceforth EK. Labor is the only factor of production, and is paid a wage w. Labor productivity in good z in country o, $b_o(z)$, is a random variable drawn from a Fréchet distribution with parameters $T_o>0$ and $\theta>1$. As in EK, competition depends on the CIF price, but here the relevant price is timeliness-adjusted: a country may win the market in a good by virtue of timely delivery rather than the lowest nominal CIF price. For each good and each bilateral route we know the optimal shipping decision from the discussion above, so it will be easy to specify the probability that o will win the competition in d.

Let C denote the set of close country pairs, such that timely delivery is possible without air shipment. Define the timeliness-adjusted iceberg $\tilde{t}_{od}(z)$ as

$$\tilde{t}_{od}(z) = \min\left[s_{od}(z), \frac{a_{od}(z)}{f(z)}\right] \qquad \forall(o,d)\notin C \tag{3a}$$

$$\tilde{t}_{od}(z) = \frac{s_{od}(z)}{f(z)} \qquad \forall(o,d)\in C \tag{3b}$$

Perfect competition implies that the FOB price is unit cost, which is $\frac{w_o}{b_o(z)}$Then the timeliness-adjusted CIF supply price $\tilde{p}_{od}(z)$ is

$$\tilde{p}_{od}(z) = \frac{w_o \tilde{t}_{od}(z)}{b_o(z)}$$

Country o will win the competition to sell good z in market d if it has the lowest timeliness-adjusted CIF price among all N countries, that is, if

$$\tilde{p}_{od}(z) = \min[\tilde{p}_{1d}(z), \ldots, \tilde{p}_{Nd}(z)]$$

As with EK, the probability that this happens is the probability that all the other prices on offer are greater than $\tilde{p}_{od}(z)$. The cdf of b_o is

$$F_o[b;z] = \Pr[B_o(z)\le b] = \exp\left(-T_o b^{-\theta}\right)$$

This reflects the assumption that all products z produced in country o have the same distribution of inverse unit labor requirements. Since $B_o \le b$ implies $\tilde{P}_{od}(z)\ge\tilde{p}$ where $\tilde{P}_{od}(z) = \frac{w_o\,\tilde{t}_{od}(z)}{B_o}$ and $\tilde{p}_{od}(z) = \frac{w_o\,\tilde{t}_{od}(z)}{b}$, it follows that

$$G_{od}[\tilde{p};z] = \Pr[P_{od}(z)\le\tilde{p}] = 1-\Pr[B_o(z)\le b] = 1-\exp\left(-T_o b^{-\theta}\right)$$

$$= 1-\exp\left(-T_o\left(\frac{\tilde{p}}{w_o\tilde{t}_{od}(z)}\right)^{\theta}\right)$$

which is essentially the same as EK's Eq. (5), with the only difference that this CDF differs by goods z, both because of variation in the demand for timeliness and variation in shipping costs.

Following EK's logic, I next derive the CDF of the price distribution in country d, which is the distribution of the minimum of prices offered by all potential suppliers o. This is

$$G_d[\tilde{p};z] = \Pr[P_d(z)\le\tilde{p}] = 1-\prod_{o=1}^{N}\left[1-G_{od}[\tilde{p};z]\right] = 1-\prod_{o=1}^{N}\exp\left(-T_o b^{-\theta}\right)$$

$$= 1-\prod_{o=1}^{N}\exp\left(-T_o\left(\frac{\tilde{p}}{w_o\tilde{t}_{od}(z)}\right)^{\theta}\right) = 1-\exp\left[\sum_{i=1}^{n} -T_o\left(\frac{\tilde{p}}{w_o\tilde{t}_{od}(z)}\right)^{\theta}\right]$$

$$= 1-\exp\left[\Phi_d(z)\,\tilde{p}^{\theta}\right]$$

where the price parameter for good z in country d is defined as

$$\Phi_d(z) = \sum_{o=1}^{N} T_o\left[w_o\tilde{t}_{od}(z)\right]^{-\theta} \tag{4}$$

Unlike in EK, this parameter varies by good, both because of the degree of timeliness preference and the origin-specific optimal transport mode. Note that since $\tilde{t}_{od}(z)$ depends only on technological and taste parameters, the price index $\Phi_d(z)$ has the same number of endogenous variable in it (namely the N wages) as in EK. The probability that o captures the market for z in d is

$$\pi_{od}(z) = \frac{T_o\left[w_o\tilde{t}_{od}(z)\right]^{-\theta}}{\Phi_d(z)} \tag{5}$$

which is similar to EK's Eq. (8).

3.4. Equilibrium

The final element of the model is market clearing. Begin by considering the demand by d for o's labor. For good z, the probability that d buys from o is $\pi_{od}(z)$. The demand functions imply that the nominal expenditure share on good z, in CIF terms, is a constant given by

$$p(z)x(z) = Y$$

Thus the expected CIF expenditure by d on good z from o is the probability that o wins the competition in z, times aggregate expenditure in d:

$$Y_{od}(z) = \pi_{od}(z)Y_d$$

Integrating over all goods gives d's expenditure on goods from o as

$$Y_{od} = Y_d\int_0^1 \pi_{od}(z)dz = \pi_{od}Y_d, \qquad \pi_{od}\equiv\int_0^1\pi_{od}(z)dz.$$

I now define national income for country o as the expenditure received by o from its sales to all markets:

$$Y_o = \sum_{d=1}^{N}\pi_{od}Y_d$$

or, substituting for Y,

$$w_oL_o = \sum_{d=1}^{N}\pi_{od}w_dL_d$$

In the EK case where timeliness is irrelevant and transport costs are the same across goods, this equation is identical, except that π_{od} is a simple function rather than an average across goods. As in EK, one wage can be taken as the numeraire, and solution of the model involves solving $N-1$ of these equations for the $N-1$ remaining nominal wages.

Solution of the model is conceptually straightforward. The solution algorithm is

1. Compute all the optimal bilateral transport modes and cutoffs, which depend only on model parameters.
2. Select a numeraire wage.
3. With the transport modes and cutoffs in hand, write out the $N-1$ factor market clearing equations,

$$w_oL_o = \sum_{d=1}^{N}\pi_{od}(\mathrm{w})w_dL_d \qquad o = 1,\ldots,N-1$$

which solve for the $N-1$ unknown wages. The remaining endogenous variables are found by substitution.

The welfare implications of the model are summarized by the aggregate price index. The ideal price index in country d associated with the utility function (1) is

$$P_d = \int_0^1 \tilde{p}_d(z)dz$$

where $\tilde{p}_d(z)$ is the timeliness-adjusted CIF price of good z which is a Fréchet distributed random variable with price parameter given by Eq. (4). To evaluate the price index I replace $\tilde{p}_d(z)$ by its expectation,

$$\int_0^\infty \tilde{p}\, dG_d(\tilde{p};z)d\tilde{p} = \gamma[\Phi_d(z)]^{\frac{-1}{\theta}}, \qquad \gamma \equiv \theta^{-1}\Gamma\left(\theta^{-1}\right)$$

where Γ is the Gamma function. The overall price index is then simply

$$P_d = \gamma \int_0^1 [\Phi_d(z)]^{\frac{-1}{\theta}} dz$$

Except for a different constant γ, this reduces to EK's price index when all goods z sold in d have the same price distribution.

3.5. Trade patterns in equilibrium

In this section, I show how relative distance affects comparative advantage. As always, comparative advantage involves the interaction of country characteristics with product characteristics. In my model, the relevant country characteristics are geographical location, and the product characteristics are timeliness-adjusted transport costs.

Consider any two origin countries 1 and 2. From Eq. (4), their relative probabilities of succeeding in selling product z in destination market d are

$$\frac{\pi_{1d}(z)}{\pi_{2d}(z)} = \frac{T_1}{T_2}\left(\frac{w_2}{w_1}\right)^{\theta}\left(\frac{\tilde{t}_{2d}(z)}{\tilde{t}_{1d}(z)}\right)^{\theta}$$

This expression emphasizes the three things that influence export success: overall productivity T, wages w, and timeliness-adjusted transport costs $\tilde{t}$. Only the latter varies by product for a particular pair of origin countries.

Suppose 1 and 2 are both close to d (one of them might even be d). Then using the expressions for $\tilde{t}$ from Eqs. (3), the relative probabilities are

$$\frac{\pi_{1d}(z)}{\pi_{2d}(z)} = \frac{T_1}{T_2}\left(\frac{w_2}{w_1}\right)^{\theta}\left(\frac{s_{2d}(z)}{s_{1d}(z)}\right)^{\theta} \tag{6}$$

The expression is the same if both origin countries are far away from d but the optimal shipping mode is surface. If the optimal shipping mode for both is air, then

$$\frac{\pi_{1d}(z)}{\pi_{2d}(z)} = \frac{T_1}{T_2}\left(\frac{w_2}{w_1}\right)^{\theta}\left(\frac{a_{2d}(z)}{a_{1d}(z)}\right)^{\theta} \tag{7}$$

An implication of Eqs. (6) and (7) is that timeliness is irrelevant to export success across products when the optimal shipping mode is the same.

Now suppose that 1 is close to d, 2 is far, and the product z is sent by ship from 2. Then

$$\frac{\pi_{1d}(z)}{\pi_{2d}(z)} = \frac{T_1}{T_2}\left(\frac{w_2}{w_1}\right)^{\theta}\cdot\left(\frac{f(z)s_{2d}(z)}{s_{1d}(z)}\right)^{\theta} \tag{8}$$

Comparing this expression to Eq. (6) illustrates the mechanism in Evans and Harrigan (2005): when goods have a high value of timeliness, and are not shipped by air, then the market share is larger for the nearby country in these goods.

Lastly, suppose that 1 is close to d, 2 is far, and the product is shipped by air from 2. Then the degree of timeliness preference is irrelevant to export success, but the relative cost of air and surface shipping becomes important,

$$\frac{\pi_{1d}(z)}{\pi_{2d}(z)} = \frac{T_1}{T_2}\left(\frac{w_2}{w_1}\right)^{\theta}\cdot\left(\frac{a_{2d}(z)}{s_{1d}(z)}\right)^{\theta} \tag{9}$$

To recap the above discussion, the following table summarizes the competitive environment in a given destination market d, from the standpoint of various potential suppliers. The cells of the table indicate the optimal shipping mode:

	Type I goods	Type II goods
Supplier near to d	Surface	Surface
Supplier far from d	Surface	Air

For Type I goods, the nearby suppliers (including suppliers in d) have an advantage in timely delivery relative to faraway suppliers. For Type II goods, all suppliers make timely delivery, but nearby suppliers have a transport cost advantage because they don't have to pay air shipping charges. In equilibrium, the only goods that will not be delivered in a timely manner will be those goods sent by surface from faraway suppliers. These are likely to be goods where timely delivery is not highly valued (if timely delivery was very valuable, then the goods would probably be produced by the nearby supplier). Turning to Type II goods, air shipped goods are likely to be ones where the cost premium for air relative to surface shipment is not too large.

Continue with the case where country 1 is near and country 2 is far from destination d. Consider two goods z^L and z^H that are "light" and "heavy" respectively in the following sense:

$$\frac{a_{2d}\left(z^L\right)}{f\left(z^L\right)} \le s_{2d}\left(z^L\right) \le s_{2d}\left(z^H\right) \le \frac{a_{2d}\left(z^H\right)}{f\left(z^H\right)} \tag{10}$$

These inequalities imply that the light good will be shipped from 2 to d by air, and the heavy good will be shipped by surface. Because 1 and d are close, both goods will be shipped from 1 to d by surface. Then dividing Eq. (9) by Eq. (8) gives

$$\frac{\pi_{1d}\left(z^L\right)/\pi_{2d}\left(z^L\right)}{\pi_{1d}\left(z^H\right)/\pi_{2d}\left(z^H\right)} = \left(\frac{a_{2d}\left(z^L\right)}{s_{1d}\left(z^L\right)} \times \frac{s_{1d}\left(z^H\right)}{f\left(z^H\right)s_{2d}\left(z^H\right)}\right)^{\theta} \tag{11}$$

To evaluate this ratio, I make two additional innocuous assumptions.

1. The degree of timeliness preference $f(z)$ is constant.
2. The two country's surface shipping cost schedules are proportional, or $s_{2d}(z) \propto s_{1d}(z)$.

Using these assumptions and substituting gives

$$\frac{\pi_{1d}\left(z^L\right)/\pi_{2d}\left(z^L\right)}{\pi_{1d}\left(z^H\right)/\pi_{2d}\left(z^H\right)} = \left(\frac{a_{2d}\left(z^L\right)}{f\left(z^L\right)s_{2d}\left(z^L\right)}\right)^{\theta} \le 1$$

or

$$\frac{\pi_{1d}\left(z^L\right)}{\pi_{1d}\left(z^H\right)} \le \frac{\pi_{2d}\left(z^L\right)}{\pi_{2d}\left(z^H\right)} \tag{12}$$

The inequality follows from the first inequality in Eq. (10), and establishes the following proposition:

Proposition 1. *In a given market, distant suppliers have a comparative advantage in lightweight goods, while nearby suppliers have a comparative advantage in heavy goods. That is, faraway countries have a relatively high market share in goods which are shipped by air.*

This is the key empirically testable prediction of the model, and the intuition is straightforward. For heavy goods, distant producers have the double disadvantage of high shipping costs and slow delivery. In lightweight goods, distant producers can match the timely delivery of nearby suppliers by using air shipment, and their competitiveness in this range of goods depends on the cost of air shipment and the utility value of timely delivery.

Proposition 1 can be understood with the help of Fig. 1. The figure incorporates the additional assumption that air shipping costs increase faster with weight than do surface shipping costs. An implication is that goods with higher value to weight ratios are more likely to be shipped by air. This commonplace observation will be confirmed in Table 5 below. In the figure, the vertical axis measures timeliness-adjusted transport costs and the horizontal index orders goods by increasing weight. The bold lower envelope $\tilde{t}_2(z) = \min\left[s_2(z), \frac{a_2(z)}{f(z)}\right]$ is the faraway country's minimized timeliness-adjusted transport cost schedule. For “light” goods $z \leq z_2$, goods are shipped by air from country 2, while “heavy” $z > \tilde{z}_2$ goods are shipped by surface regardless of which country sells them. Since $\frac{s_1(z)}{f(z)} = \tilde{t}_1(z) < \tilde{t}_2(z)$ for all z, the nearby supplier always has an absolute transport cost advantage, but this cost advantage is smaller for goods that are shipped by air from country 2. The Proposition follows immediately, since in the model comparative advantage is a monotonic function of differences in relative transport costs across goods.

These insights are further developed in a simplified three country version of the model (three is the smallest number of countries required for distance to affect comparative advantage) which is presented in the online Appendix. In the three country model, two countries are near each other, while the third country is more distant. In equilibrium, the more remote country has lower wages, and specializes in lightweight goods which are air shipped. Falling air transport costs benefit all countries, but the distant country benefits disproportionately. In addition, falling air transport costs lead to greater specialization in lightweight goods by the faraway country. Thus in equilibrium distance matters *more* to specialization rather than less when some transport costs fall, in the sense that market shares across goods are more strongly correlated with relative distance.

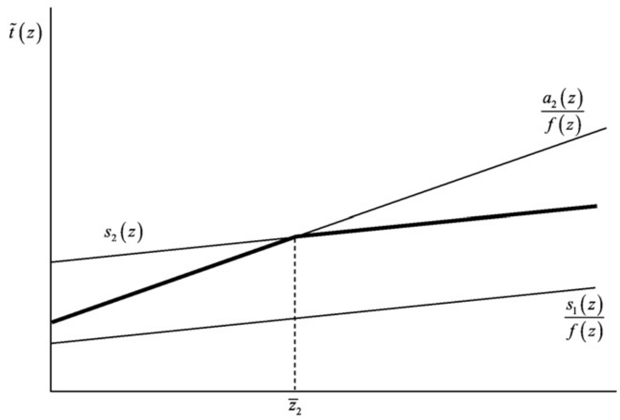


Fig. 1. Transport costs for nearby and faraway sellers in a given market. Notes to Fig. 1: goods are ordered from lightest to heaviest, so that all transport costs are increasing in z. The bold lower envelope $\tilde{t}_2(z) = \min\left[s_2(z), \frac{a_2(z)}{f(z)}\right]$ is the faraway country's minimized timeliness-adjusted transport cost schedule. For “light” goods $z \leq z_2$, goods are shipped by air from country 2, while “heavy” goods are shipped by surface regardless of which country sells them.

3.6. The model's predictions for trade data

For any given level of wages, the model delivers predictions about the cross-section of goods imported by a given country. It is these predictions which will be the focus of the empirical analysis, with the United States as the importing country. I will focus on Proposition 1: nearby countries will have higher market shares in heavy goods and faraway countries will specialize in light goods.

As noted in Section 2, the import data are reported at the 10-digit Harmonized System (HS) level, which is extremely detailed, with over 14,000 codes in 2003. These 10-digit categories will be the empirical counterpart of the goods in the model in what follows.

The import data does not report prices, but since it reports both value and quantity I can calculate unit values, defined as the dollar value of imports per physical unit. Since shipping costs depend primarily on the physical characteristics of the good rather than on its value, low value goods will be “heavy” in the sense of having a higher shipping cost per unit of value.[8] For example, consider shoes. Quantities of shoes are reported in import data, and the units are “number” as in “number of shoes”. Expensive leather shoes from Italy and cheap canvas sneakers from China weigh about the same, but the former will have a much higher unit value. In the context of the model, Italian leather shoes are “lighter” than Chinese fabric sneakers, in the economically relevant sense that the former have lower transport costs as a share of value. It is important to keep in mind that it is meaningless to compare unit values when the units are not comparable: dollars per number of shoes is not comparable to dollars per barrel of oil or dollars per square meter of fabric.

The model's predictions about specialization can be expressed in two ways. The first is in terms of relative quantities: nearby countries have a higher market share in heavy goods than lightweight goods. While it would be difficult if not impossible to classify goods by weight, the data does report which goods are shipped by air, so I can directly test the alternative statement of Proposition 1: faraway countries have a relatively high market share in goods which are shipped by air. Testing this formulation of the theory will be the first empirical exercise undertaken below.

A serious objection to the above strategy is that there are many reasons unrelated to weight why a country might have a high market share in a particular good. For example, Canada has a very high market share in lumber and wood products, which have relatively low value per kilo and are almost never shipped by air; since Canada is adjacent to the United States this would seem to support the model. But of course it would be absurd to explain trade in lumber while ignoring the fact that Canada is covered in trees.

Consequently, I conduct a second empirical exercise that focuses on the model's predictions about unit values of goods which are actually imported. For a particular group of goods, the model predicts a relationship between unit values and distance: imports from nearby countries should have lower unit values than imports from more distant countries. That is, the deviation of unit values from the group mean should be positively related to distance from the U.S.

To state this a bit more formally, suppose that a given HS code contains goods of varying weights, which we can order from lightest to heaviest. According to the model, each good within the HS code will be provided by one country, with the winner of the good-by-good competition being stochastic. Thus, a country that exports in this code must have won at least one competition. Conditional on exporting in this code, nearby countries are more likely to have won competitions among the heavier goods, and more distant countries are likely to have won in the lighter goods.

[8] The relationship between shipping cost and shipment value is estimated by Hummels and Skiba (2004), Table 1. They find that shipping costs increase less than proportionately with price.

Note that this formulation of the model's prediction effectively controls for other, non-weight related determinants of specialization (the "Canadian trees" problem). This is because the prediction about the cross-section of unit values within an HS code is conditional on countries exporting in that category at all.

4. Airplanes and trade: empirical evidence

The trade data that was described in Section 2 above will now be used to test the theory laid out in Section 3. In addition to data on imports and distance, I also use data on macro variables such as real GDP per capita and aggregate price level, which come from the Penn World tables.[9]

4.1. Statistical results: market shares

The first empirical exercise is focused on the prediction that exporters that are far from the United States will have a relatively high market share of U.S. imports in goods which are shipped by air. The geography of North America suggests an obvious empirical definition of "near" and "far": Mexico and Canada are near the United States, while all other exporters are far. Thus, the prediction becomes Mexico and Canada will have lower shares of U.S. imports in products which the rest of the world ships by air.

As a preliminary to the statistical model, Plot 1 illustrates the relationship between the Mexico–Canada market and the share of non-NAFTA imports that arrive by air ("air share"), for 2003. There is a clear negative relationship: when the non-NAFTA air share is low, the NAFTA market share is on average higher than when the non-NAFTA air share is high. This is exactly what the theory predicts.

The prediction can be tested more formally using the following linear regression equation:

$$\pi_i^F = \beta_0 + \beta_1 a_i + \varepsilon_i \quad (13)$$

where

$\pi_i^F =$ Faraway exporters' aggregate share of the U.S. import market of product i

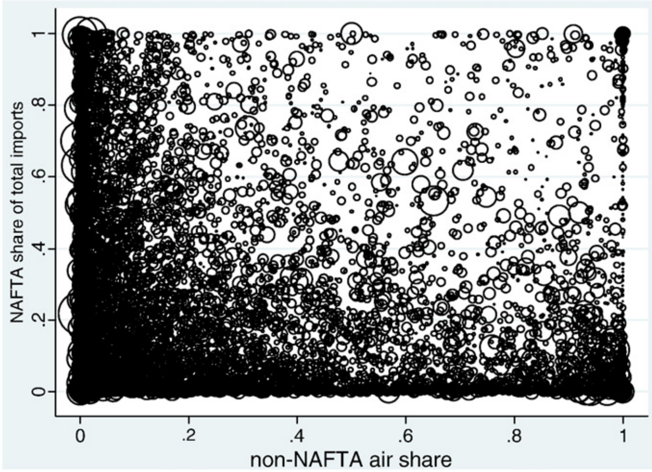
$a_i =$ share of product i imports that arrive by air from exporters other than Canada and Mexico

The prediction of the model is $\beta_1 > 0$. The results are reported in Table 2.

The following issues in estimating Eq. (13) are important:

1. Measurement of a_i: in the data, a given good from a given exporter is almost invariably shipped entirely by air or entirely by surface. Aggregating across all faraway exporters (which is how a_i is constructed) introduces some heterogeneity, but about half of all goods have an air share of either zero or one. To account for this, I report two specifications. The first treats a_i as a continuous variable. The second creates two indicators for $a_i = 1$ and $a_i = 0$ respectively.
2. Omitted variables: in addition to being near the U.S., Canada and Mexico also belong to NAFTA starting in 1994, which means they have a tariff preference compared to faraway countries which differs across products and which may be correlated with a_i. To control for this I include the average tariff for faraway countries (which is equivalent to the Canada–Mexico tariff preference) in all regressions, though to save space I do not report the coefficients. Unreported results show that excluding tariffs from the regressions has no effect on the parameter of interest.

[9] The Penn World table data are available at http://pwt.econ.upenn.edu/php_site/pwt_index.php.



Plot 1. NAFTA share of U.S. imports vs. non-NAFTA air shipment share, 2003. Notes to Plot 1 Each point corresponds to an HS10 product, and shows the share of total imports of that product that comes from Canada and Mexico plotted against the share of non-NAFTA imports of that product that arrives by air. Circle sizes are proportional to the square root of total imports in the HS10 code.

3. Estimation sample: pooling across all products and exporting countries may obscure important variation in β_1. To account for this issue I estimate the model on various sub-samples in addition to the full sample. First, I break products down into manufacturing products (SITC 6 manufactured goods, SITC 7 machinery and transport equipment, and SITC 8 miscellaneous manufactures) and non-manufacturing products. Second, I pool only high-income exporters (defined by the World Bank classification in each year), so that β_1 is identified by the market share difference between Canada and all other high-income exporters. Finally, I pool only middle-income exporters, so that β_1 is identified by the market share difference between Mexico and all other middle-income exporters.
4. Error structure: since market shares by construction are between zero and one, the OLS assumption that the error term has infinite range is not valid, and OLS fitted values may lie outside the unit interval. To control for this, Table 2 reports results from a double-sided Tobit specification which ensures that all fitted values lie in the unit interval. All covariance matrices are computed using the heteroskedastic-robust White estimator.

Table 2 reports many numbers, but the key message is told by the numbers highlighted in bold, which report estimates of the airshare effect in 2003. I focus my discussion here on the Tobit specification of Table 2, though it should be noted that the estimated effects are somewhat smaller in the (simpler but mis-specified) OLS specification reported Table A4 in the online Appendix.

The top row of Table 2 shows that in 2003, for the full sample the coefficient on airshare was 0.09. The interpretation is that in moving from goods which were completely shipped by surface to those completely sent by air, the average market share of faraway exporters went up by 9 percentage points. The specification that looks just at the extremes of a_i implies an effect of 14 percentage points: goods shipped solely by air had an average 13.4 percentage point higher market share relative to Mexico and Canada than goods shipped entirely by surface. These are economically big effects. The rest of Table 2 shows that the effect is strongest for high-income exporters of manufactured products: compared to Canada, other rich exporters of air shipped manufactured products have a 22.9 percentage point higher market share in goods sent by air compared to goods sent by surface (central panel of table, second column with items in bold). By contrast, the effect is not statistically significant from zero for middle-income exporters of non-manufactured

Table 2
Tobit market share regressions.

	All exporters				High-income exporters				Middle-income exporters			
	1990	1995	2000	2003	1990	1995	2000	2003	1990	1995	2000	2003
All products, continuous air share												
Air share	0.091	0.076	0.082	**0.090**	0.105	0.112	0.134	**0.166**	−0.093	−0.083	−0.123	**−0.096**
	8.3	*7.1*	*8.0*	***8.6***	*9.5*	*10.7*	*13.0*	***15.6***	*−3.7*	*−4.2*	*−6.8*	***−5.3***
All products, binary air share indicator												
Air share = 0	0.002	−0.001	0.016	−0.002	−0.012	−0.017	−0.010	−0.032	0.189	0.181	0.194	0.184
	0.2	*−0.1*	*2.1*	*−0.3*	*−1.5*	*−1.9*	*−1.1*	*−3.4*	*11.7*	*14.8*	*17.5*	*17.5*
Air share = 1	0.157	0.081	0.130	0.132	0.145	0.103	0.150	0.172	0.204	0.181	0.180	0.218
	7.9	*4.5*	*7.3*	*7.1*	*7.4*	*5.9*	*9.1*	*10.3*	*5.6*	*6.3*	*6.3*	*7.3*
(Air share = 1)–(air share = 0)	0.155	0.082	0.114	**0.134**	0.157	0.120	0.160	**0.204**	0.015	−0.000	−0.014	**0.034**
	7.5	*4.4*	*6.1*	***7.0***	*7.7*	*6.3*	*8.9*	***11.0***	*0.4*	*−0.0*	*−0.5*	***1.1***
Sample size	12,537	13,659	14,469	14,783	12,005	12,918	13,622	13,701	7,093	8,829	10,572	11,614
Manufacturing products, continuous air share												
Air share	0.129	0.111	0.110	**0.110**	0.133	0.134	0.154	**0.181**	−0.052	−0.044	−0.081	**−0.059**
	12.1	*10.3*	*10.4*	***10.2***	*12.7*	*12.2*	*14.5*	***16.7***	*−1.9*	*−2.0*	*−4.1*	***−3.1***
Manufacturing products, binary air share indicator												
Air share = 0	−0.016	−0.020	0.014	−0.009	−0.032	−0.037	−0.018	−0.036	0.151	0.134	0.160	0.159
	−1.9	*−2.2*	*1.7*	*−1.0*	*−3.6*	*−3.6*	*−1.7*	*−3.2*	*8.6*	*10.2*	*13.2*	*13.9*
Air share = 1	0.232	0.138	0.155	0.165	0.205	0.135	0.155	0.193	0.198	0.165	0.168	0.228
	11.2	*7.2*	*8.3*	*8.2*	*10.5*	*7.4*	*9.2*	*11.2*	*4.9*	*5.2*	*5.4*	*6.8*
(Air share = 1)–(Air share = 0)	0.248	0.157	0.141	**0.173**	0.237	0.172	0.173	**0.229**	0.046	0.031	0.008	**0.070**
	11.4	*7.7*	*7.1*	***8.2***	*11.3*	*8.8*	*9.1*	***11.5***	*1.2*	*0.9*	*0.3*	***2.0***
Sample size	9042	9783	10,453	10,610	8838	9495	10,104	10,120	5335	6557	7852	8526
Non-manufacturing products												
Air share	−0.065	−0.033	−0.022	**0.016**	−0.026	0.044	0.046	**0.101**	−0.160	−0.116	−0.133	**−0.125**
	−2.0	*−1.1*	*−0.8*	***0.6***	*−0.8*	*1.3*	*1.4*	***3.1***	*−2.6*	*−2.1*	*−2.6*	***−2.5***
Non-manufacturing products, binary air indicator												
Air share = 0	0.04	0.011	0.015	0.008	0.040	0.004	0.015	−0.019	0.230	0.218	0.136	0.157
	2.3	*0.6*	*0.9*	*0.5*	*1.9*	*0.2*	*0.8*	*−0.9*	*4.9*	*5.5*	*4.1*	*5.1*
Air share = 1	−0.060	−0.099	0.020	0.028	−0.039	−0.037	0.100	0.085	0.184	0.164	0.116	0.102
	−1.3	*−2.4*	*0.5*	*0.7*	*−0.8*	*−0.8*	*2.2*	*2.0*	*2.2*	*2.2*	*1.6*	*1.4*
(Air share = 1)–(Air share = 0)	−0.102	−0.109	0.005	**0.020**	−0.079	−0.042	0.085	**0.104**	−0.046	−0.054	−0.020	**−0.055**
	−2.3	*−2.7*	*0.1*	***0.5***	*−1.7*	*−0.9*	*1.9*	***2.4***	*−0.6*	*−0.8*	*−0.3*	***−0.8***
Sample size	3495	3876	4016	4173	3167	3423	3518	3581	1758	2272	2720	3088

Notes to Table 2: estimation of Eq. (13) in the text. Dependent variable is aggregate market share in U.S. imports of exporters other than Canada and Mexico. Unit of observation is an HS 10 code. Robust *t*-statistics are in *italics*.
For each sample, two specifications are estimated: with a continuous measure of air share, and with two indicators for air share = 0 and 1. In this second specification, the Tables report the point estimate and *t*-statistic on the difference between the coefficients on the indicators. Estimator is double-sided Tobit, with upper and lower censoring of 1 and 0 respectively. The most interesting numbers in the Tables are rendered in **bold**.

products (last panel of table, last column with items in bold); the effect for high-income exporters of non-manufactured goods is 0.101, about the same as the overall effect.

In summary, Table 2 shows that the interaction of distance and transport mode has an important influence on the source of U.S. imports, at least for high-income exporters. (The effect is weak or non-existent for middle-income exporters). The effect is strongest in manufactured goods shipped by high-income exporters, which were more than 40% of U.S. imports in 2003. This is a striking evidence in support of Proposition 1: in both the model and the data, faraway countries have a relatively high market share in goods which are shipped by air.

4.2. Statistical results: unit values

In this section I focus on what the model predicts about the price of imports across source countries: imports from faraway countries will have higher f.o.b. unit values than goods shipped from nearby countries. Statistically, I investigate this by looking at variation in unit values across exporters within 10-digit HS categories. The econometric model I use is

$$v_{ic} = \alpha_i + \beta d_c + \text{other controls} + \varepsilon_{ic} \qquad (14)$$

where

$v_{ic} =$ log unit value of imports of product *i* from country *c*
$\alpha_i =$ fixed effect for 10-digit HS code *i*
$d_c =$ distance of *c* from United States

Note that import values are measured f.o.b, so they do not include transport charges. The model predicts $\beta > 0$ in Eq. (14): across exporters within a 10-digit commodity category, more distant exporters will sell products with higher unit values, controlling for other observable country-specific factors which might affect unit values. When the units are kilograms, then the prediction for unit values is a prediction about the value–weight ratio.

The fact that Eq. (14) uses only cross-exporter variation within each 10-digit HS differentiates it from Eq. (13). The advantage of using a within-product estimator is that it controls for which goods a country exports: if a country does not export product *i* to the US, then that country's distance from the US is (appropriately) irrelevant to the effect of distance on unit values within-product *i*. Product fixed effects also control for differences in physical characteristics of products, making it possible to meaningfully pool information from microchips and potato chips.

The basic measurement of distance is distance in kilometers between the US and the exporting countries. The model, and common sense, give no reason to expect that any distance effect is linear, so I adopt a piecewise formulation which allows for, but does not impose, an approximately linear distance effect. Thus I measure distance by five indicator variables, based on grouping countries into similar distances from the US:

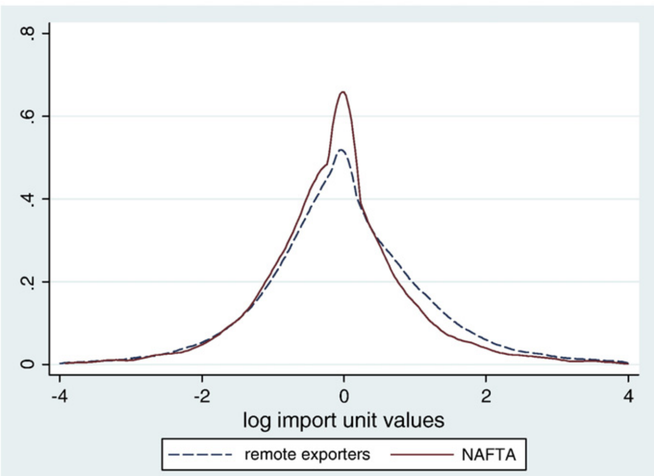
adjacent to the US (Mexico and Canada).
between 1 and 4000 km (Caribbean islands and the northern coast of South America).
between 4000 km and 7800 km (Europe west of Russia, most of South America, a few countries on the West Coast of Africa)
between 7800 km and 14,000 km (most of Asia and Africa, the Middle East, and, Argentina/Chile)
over 14,000 km (Australia/New Zealand, Thailand, Indonesia, and Malaysia/Singapore).

In some of the regressions, I aggregate the distance classes into near (less than 4000 km) and far. I also include a dummy for if a country is landlocked.

There are other factors that could affect unit values within 10-digit products, and I control for some of these. *Other controls* include

tariffs, measured as *ad valorem* percentage, which should have a negative sign to the extent that trade costs are borne by producers.
macro indicator of comparative advantage (log aggregate real GDP per worker, from the Penn World Tables). My model is silent on how these aggregate measures might affect prices, but if more advanced countries specialize in more advanced and/or higher quality goods, we would expect positive effects of these variables on log unit values. Evidence of such effects is reported by Schott (2004), Hallak (2006) and Hummels and Klenow (2005).

Before turning to estimation of Eq. (14), it is informative to look at a plot of the data. Plot 2 shows the distribution of log U.S. import unit values from two groups of exporters: the NAFTA countries Canada and Mexico, and exporters whose goods cross the Atlantic or Pacific Ocean. I first remove the HS10 mean log unit values, so that the plot shows deviations from product-specific averages. There are two key features visible in Plot 2. The first is that the distribution for remote exporters is clearly shifted to the right relative to the distribution for Canada and Mexico: as predicted by the model, goods have higher unit values when they travel a greater distance. The second notable feature of the data is the extremely wide scale of the horizontal axis, from −4 to +4 (a few even more extreme values are trimmed in the interests of readability). This great range of log unit values is suggestive of substantial heterogeneity even within narrowly-defined HS10 categories.



Plot 2. Densities of log import unit values, 2003. Notes to Plot 2 Kernel densities of log import unit values, expressed as deviations from HS10 means. Density labeled NAFTA is all log unit values from Canada and Mexico, density labeled "remote exporters" includes observations from exporters more than 4000 km from the United States (the plot excludes observations from exporters less than 4000 km other than Canada/Mexico).

Tables 3 and 4 report the results of estimating Eq. (14).[10] For each year, log unit value is regressed on the controls as well as fixed effects for 10-digit HS codes. In the interest of reducing the quantity of numbers presented, I report results for only four selected years (1990, 1995, 2000, and 2003), although all regressions were estimated on all 14 years from 1990 to 2003 (complete results available on request). Each column shows results for a single year's regression, with *t*-statistics in *italics*.

The specifications in Tables 3 and 4 differ in the definition of the dependent variable. Table 3 uses the broadest definition of unit value, and includes all observations for which units are reported, whether those units are number, barrels, dozens, kilos, or something else. Table 4 includes only observations for which weight in kilos is reported, so the unit value in the Table 4 is precisely the value–weight ratio for all of the observations.

Tables 3 and 4 include all available observations, while Appendix Tables A4 and A5 restrict the sample in two ways. First, very small and potentially erratic observations are eliminated by dropping all import records of less than $10,000. Second, to focus attention on manufactured goods, Tables A4 and A5 include only HS codes that belong to SITC 6, 7, and 8.

Tables 3 and 4 show that the effect of distance on unit values is large, robust, and statistically significant. The first column for each year in Tables 3 and 4 has a single indicator for distance greater than 4000 km from the United States. As the first row of Table 3 shows, for the full sample unit values are around 30 log points higher when they come from more distant locations. The effect is even larger when the sample is restricted to observations with units in kilos, with the distance effect between 40 and 50 log points (first row, Table 4).

The second four rows of Tables 3 and 4 break down distance into a larger number of categories, with Mexico/Canada as the excluded category. A striking feature of these results is the non-monotonic effect of distance. For example, in Table 3 in 2003 the closest non-adjacent distance category is associated with unit values 15.9 log points higher than Mexico/Canada, an effect which jumps to 52 log points for the next category, before falling back to 10.4 and 16.8 log points in the final two distance categories. The pattern is similar in Table 4, but the effects are substantially larger. The additional effect of being landlocked is also large, ranging between 18 and 55 log points across specifications in Tables 3 and 4.

The estimated effects of distance are invariably larger in Table 4 than in Table 3. This discrepancy is supportive of the model's predictions, since the dependent variable in Table 4 (log value/kilo), is more closely connected to the theory than the dependent variable in Table 3 (log unit value). To the extent that different units within a product have different weights (which they often do), one would expect a weaker connection between unit value and distance.

The puzzling non-monotonicity of the distance effect on unit values probably reflects imperfectly measured country characteristics that affect unit values and are correlated with distance, since the 4000–7800 range includes many of the most developed countries (including all of the EU exporters). The importance of development in affecting unit values was found in Schott (2004), Hallak (2006) and Hummels and Klenow (2005), and is confirmed here: a higher aggregate productivity level raises unit values with a large and significant elasticity, between 0.4 and 0.55, in every regression in

[10] All regressions are estimated by OLS, with product fixed effects and robust standard errors. Note that standard errors are *not* adjusted for clustering by exporting country, despite the fact that cross-product correlation of errors within an exporter is *a priori* plausible. For an explanation, see the online Appendix.

Table 3
Regression of U.S. import unit values on distance and other controls, all available observations.

	1990		1995		2000		2003	
More than 4000 km	0.319		0.377		0.317		0.323	
	26.9		*30.7*		*26.8*		*28.0*	
1–4000 km		−0.020		0.078		0.231		10.159
		−1.0		*3.9*		*11.4*		*8.0*
4000–7800 km		0.551		0.646		0.495		0.520
		38.6		*46.7*		*38.2*		*39.9*
7800-14,000 km		0.043		0.124		0.159		0.104
		2.8		*8.1*		*10.7*		*7.0*
More than 14,000 km		0.138		0.172		0.203		0.168
		7.1		*9.3*		*11.4*		*9.7*
Log Y/L	0.510	0.365	0.508	0.363	0.498	0.395	0.546	0.415
	78.4	*60.2*	*87.1*	*63.5*	*90.3*	*67.2*	*103.8*	*74.4*
Landlocked	0.388	0.236	0.556	0.373	0.406	0.300	0.499	0.360
	17.9	*10.7*	*26.1*	*17.4*	*21.0*	*15.3*	24.9	*17.7*
Tariff	−0.013	−0.012	−0.010	−0.011	−0.002	−0.002	−0.006	−0.005
	−4.5	*−4.6*	*−7.8*	*−8.9*	*−1.8*	*−2.4*	*−6.7*	*−5.3*
R^2 within	0.113	0.142	0.107	0.137	0.102	0.114	0.120	0.136
N	88,984		108,837		121,830		127,602	
HS codes	11,815		13,131		13,788		14,103	

Notes to Table 3: estimates of Eq. (14) in the text. For each year, log U.S. import unit value is regressed on indicators for exporter distance from the US, other controls, and fixed effects for 10 digit HS codes. Estimation is by OLS, *t*-statistics clustered by HS code are in italics. Y/L is aggregate real GDP per worker of the exporter, landlocked is an indicator for the exporter having no port, and tariff is ad valorem percentage. *N* is sample size, “HS codes” is the number of 10 digit HS code fixed effects, and “R^2 within” is the R^2 after removing HS10 means from the data.

Tables 4 and 5. The very large effect of the 4000–7800 km category on unit values is suggestive of a non-linear effect of log GDP on unit values, and/or some other feature of the EU countries that leads them to specialize in high unit value products within HS codes. The fact that distance is correlated with GDP per capita is a fundamental feature of the data, and in the context of a within-product data specification like Eq. (14) it is not possible to more precisely isolate the separate effects of distance and development on unit values.

Although the tariff effects are not the focus of the paper, it is interesting that they are consistently estimated to be small (between −0.013 and −0.002), negative and statistically significant. These negative effects are consistent with the US being a large market for most exporters, and are suggestive of small terms of trade gain from protection.

Appendix Tables A4 and A5repeat the specifications of Tables 3 and 4 for a narrower sample, excluding non-manufacturing imports as well as very small observations (value of less than $10,000). The results are largely consistent with Tables 3 and 4, which confirm that the overall results are not driven by a small number of observations or by non-manufacturing SITC categories.

4.3. Statistical results: the shipping mode choice

A final empirical question concerns the choice between air and surface shipment by remote exporters. According to the model, the mechanism behind the within-product specialization documented in Tables 3 and 4 is that remote exporters are more likely to ship goods by air, and that these goods are “light” in the economically relevant sense of having low air transport costs as a share of value. Since transport charges per unit are more closely related to weight than value (as common observation as well and Hummels and Skiba (2004) show), transport charges as a share of value are declining in a goods value/weight ratio. Therefore, according to the model air shipment should be the mode of choice only for high value/weight (or “light”) products from distant locations. In this section I test this prediction.

Table 4
Regression of U.S. import value/kilo on distance and other controls, all available observations.

	1990		1995		2000		2003	
More than 4000 km	0.408		0.520		0.474		0.454	
	35.9		*41.3*		*39.6*		*39.1*	
1–4000 km		0.203		0.283		0.315		0.278
		10.7		*16.0*		*17.8*		*15.6*
4000–7800 km		0.609		0.741		0.620		0.636
		44.0		*52.4*		*45.4*		*48.0*
7800–14,000 km		0.347		0.465		0.465		0.358
		23.1		*31.0*		*31.1*		*23.4*
More than 14,000 km		0.304		0.423		0.423		0.354
		16.1		*23.5*		*23.7*		*20.0*
Log Y/L	0.432	0.367	0.450	0.381	0.440	0.397	0.505	0.422
	67.7	*58.3*	*77.1*	*63.7*	*82.1*	*67.0*	*97.0*	*73.3*
Landlocked	0.436	0.352	0.543	0.444	0.464	0.412	0.554	0.461
	18.1	*14.5*	*23.9*	*19.5*	*22.7*	*20.0*	*27.9*	*73.3*
Tariff	−0.011	−0.013	−0.008	−0.010	−0.004	−0.005	−0.005	−0.005
	−8.7	*−10.7*	*−6.5*	*−7.7*	*−3.5*	*−4.6*	*−6.7*	*−6.0*
R^2 within	0.164	0.183	0.167	0.186	0.156	0.162	0.181	0.225
N	52,028		66,366		74,271		78,910	
HS codes	7422		8518		8910		9139	

Notes to Table 4: estimates of Eq. (14) in the text. For each year, log U.S. import value/kilo is regressed on indicators for exporter distance from the US, other controls, and fixed effects for 10 digit HS codes. Estimation is by OLS, *t*-statistics clustered by HS code are in italics. Y/L is aggregate real GDP per worker of the exporter, landlocked is an indicator for the exporter having no port, tariff is ad valorem percentage. *N* is sample size, “HS codes” is the number of 10 digit HS code fixed effects, and “R^2 within” is the R^2 after removing HS10 means from the data.

Table 5
Probit of shipment mode choice by non-NAFTA exporters.

	1990	1995	2000	2003
Log value/kilo	0.182	0.202	0.234	0.221
	10.9	*13.3*	*17.5*	*16.3*
4000–7800 km	−0.068	−0.001	0.151	0.078
	−1.4	*0.0*	*1.9*	*1.0*
7800–14,000 km	−0.181	−0.156	−0.054	−0.074
	−5.6	*−3.5*	*−0.7*	*−1.1*
More than 14,000 km	−0.112	−0.109	−0.053	−0.078
	−5.7	*−3.0*	*−0.7*	*−1.3*
Log Y/L	−0.025	−0.012	−0.004	0.003
	−0.9	−0.5	−0.1	0.1
Landlocked	0.093	0.113	0.091	0.098
	1.1	*1.3*	*1.2*	*1.1*
Sample size	23,149	30,116	33,623	35,955
HS codes	3541	4479	4917	4854
p−Values for instrument validity tests				
Exogeneous?	0.75	0.89	0.68	0.84
Weak?	0.00	0.00	0.00	0.00

Notes to Table 5 maximum likelihood estimation of Eq. (15) in the text for all exporters except Mexico and Canada. Coefficients are marginal effects, evaluated at sample mean. Robust *t*-statistics clustered by exporting country in *italics*. Dependent variable is $a_{ic}=1$ if product *i* is shipped by air from exporter *c*. Log value/kilo is endogenous, instrument is log of average value/kilo by HS10 from Canada and Mexico. Y/L is aggregate real GDP per worker of the exporter, landlocked is an indicator for the exporter having no port. *p*-Values are the results of χ^2 tests for valid instruments. The "exogenous?" row tests the null that the instrument can be excluded from the second stage, while the "weak?" row tests the null that the instrument has no marginal explanatory power in the first stage.

The implication of the model that nearby countries will not choose air shipment is confirmed by Chart 3: virtually all U.S. imports from Canada and Mexico come by surface transport. A challenge in testing the theory that air shipment is chosen for high value/weight goods is the endogeneity between value and shipment mode: the theory says that consumers are willing to pay a premium for air shipped goods, which is why suppliers (sometimes) choose air shipment. Thus, I need an instrument for a product's value/weight: a variable that is correlated with value/weight but unrelated to shipment choice. The fact that Canada and Mexico don't use air shipment suggests a potentially powerful instrument, which is value/weight of imports from Mexico and Canada. For a given HS10 code *i* and a given non-NAFTA exporter *c*, the value/weight of Mexican–Canadian good *i* is likely to be correlated with value/weight of good *i* from *c*, but should have no independent effect on the shipping mode choice from *c*.[11]

To test the mechanism that remote exporters are more likely to ship high value/weight goods by air, I estimate a discrete choice model of the shipping mode choices of all exporters except NAFTA. Defining the indicator variable $a_{ic}=1$ if product *i* is shipped by air from exporter *c*, I estimate the following probit model for each year:

$$\Pr(a_{ic} = 1 \mid data) = F(\beta_0 + \beta_1 p_{ic} + \boldsymbol{\beta}_2 \mathbf{x}_c) \quad (15)$$

where p_{ic} is the log value per kilo of imports of product *i* from country *c*, $\mathbf{x}_c$ is a vector of country characteristics including distance indicators and log aggregate productivity, and *F* is the standard normal CDF.

The air shipment indicator a_{ic} is coded as 1 if the share of imports sent by air for that product-country is greater than 0.9, and a_{ic} is coded as 0 is the share is less than 0.1. The estimation sample is substantially smaller than in the previous section because the following observations are excluded:

imports from NAFTA
products where weight in kilos is not reported
products not exported by NAFTA (needed for instrument)
products with non-trivial share of NAFTA imports arriving by air (very few products)
Observations where share of goods that arrive by air is between 0.1 and 0.9.

The estimator is maximum likelihood, with p_{ic} instrumented by the average value of p_i from Mexico and Canada. This is a strong instrument, with a simple correlation of around 0.6 between the instrument and p_{ic}. The estimated covariance matrix allows for heteroskedasticity and clustering by country.[12] Distance is measured using the same categories as in the previous section, but since NAFTA observations are excluded from the estimation, the excluded dummy variable becomes the distance category of 1–4000 km. Results are reported in Table 5.

Looking at the bottom two rows of the table first, the instrument appears valid: the null that there is no correlation in the first stage is rejected, while the null that the instrument can be excluded in the second stage cannot be rejected. Turning to the marginal effects, there is strong evidence that higher value/weight goods are more likely to be shipped by air: a 1% increase in value/weight leads to about a 0.2 percentage point increase in the probability of air shipment. Given the huge range in value/weight,[13] this is a very large effect, and it is tightly estimated. By contrast, the other explanatory variables (distance, landlocked, and aggregate productivity) do not have statistically significant effects, especially in the later years.

4.4. Summarizing the evidence

Applying Proposition 1 to the United States, the model of Section 2 predicts that more distant exporters to the U.S. will specialize in lightweight goods which are shipped by air. The empirical analysis evaluated this prediction in three ways: by looking at market shares of different goods, within-product variation in unit values across exporters, and the determinants of shipping mode.

In Section 4.2, I showed that Canada and Mexico have market shares that are on average about 9 percentage points higher in goods that other countries do not ship by air. This aggregate effect is mainly driven by the difference between Canada and other high-income exporters, especially in manufactured goods, where the effect is around 20 percentage points. These results are reported in Table 2.

In Section 4.3, I focused on within-category variation in import unit values. Thus the statistical model of Eq. (14) asks the question: if a country exports a good to the US, is the unit value of that good

[11] For brevity, I will sometimes use "NAFTA" as a synonym for "Mexico and/or Canada", although the NAFTA agreement was not in force in the early years of my sample.

[12] See Appendix for an important caveat about estimation of the covariance matrix.

[13] In 2003, the 5th–95th percentile range of log value/weight is [−0.2,5], which is a factor of more than 120 in levels.

related to distance? The answer is yes, as shown in Tables 3 and 4. If we focus on the final year of the sample, we find that exports that arrive from destinations more than 4000 km from the U.S. (that is, from sources other than Mexico, Canada, and the Caribbean) have import unit values between 25 and 40 log points higher than those from nearby sources.

A puzzling finding is that the effect of distance on unit values is non-monotonic, with the effect seemingly peaking in the distance range of 4000–7800 km. Since this distance category includes Europe, the large estimated coefficients may be conflating the effect of distance and Europe's comparative advantage in producing high-quality goods. This is an important caveat for interpreting the size of the distance effect but does not overturn the strong relationship between distance and import unit value.

The results of Tables 3 and 4 confirm the importance of distance for unit values, but they don't say anything about the role of shipment mode choice. Table 5 fills in this gap, with the unsurprising finding that air shipment is strongly related to value/weight. Thus, we can conclude that the findings of Tables 3 and 4 are driven at least in part by the mechanism studied in the model: remote exporters specialize in lightweight goods which are shipped by air.

Lastly, the results confirm the results of Schott (2004), Hallak (2006), and Hummels and Klenow (2005) that there is an important relationship between import unit values and the level of development, which probably reflects a comparative advantage that rich countries have in high-quality goods.

5. Conclusion

This paper has focused on the interaction between trade, distance, transport costs, and the choice of shipping mode. In the theory model, I showed how the existence of airplanes implies that countries that are far from their major export markets will have a comparative advantage in lightweight goods. This prediction is strongly supported by the data.

In the empirical sections, I documented the heterogeneity across regions and goods of the prevalence of air shipment in US imports. The statistical analysis finds three strong and robust empirical relationships that support the model. The first is that Canada and Mexico have much higher market shares in goods which other countries do not ship by air. The second is that U.S. imports from remote suppliers have unit values on the order of a third higher than those from nearby countries. The third (and least surprising) result is that the probability of air shipment is strongly related to distance and unit value.

Distance is not dead, and the theory and empirical results of this paper suggest that it will not be expiring any time soon. The fall in the relative cost of air shipment implies that relative distance may become even more important in determining comparative advantage, as nearby countries increasingly trade heavy goods with each other while trading lighter goods with their more distant trading partners.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jinteco.2010.07.002.

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