Trade and Transportation

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Introduction

The price of transporting a good from the point of production to the point of consumption is but one of many trade "barriers" or "frictions" that prevent the perfect integration of markets. Unlike physical impediments (such as distance) that are truly exogenous, and policy barriers that are subject to political calculus, transportation prices are endogenous outcomes of a market process. As such, transportation prices are influenced by (derived) demand, cost and market characteristics. Consequently, these features affect trade along the intensive margin (trade volumes) and the extensive margin (trade pattern) through their impact on transportation prices.

The following pages present a model of trade and transportation designed to capture and elucidate these connections. The model of trade follows Melitz and Ottaviano (2005) in combining quasi-linear preferences exhibiting love of variety and manufacturing firms with heterogeneous costs. The transportation sector is linked to the trade model through its effect on the exclusive costs of exporting.

This project is a work in progress—some parts of the model need to be completed, expanded and refined. In addition, this model needs to be connected to an empirical framework for testing and estimation.

The Model

The model consists of two countries (A,B), one homogenous good (produced and consumed in both countries), and a differentiated good with a continuum of varieties produced by firms with heterogeneous costs. The timing of the models is as follows:

Stage 1: Transportation firm(s) allocate capacity and set freight rates; firms can invest in new capacity in the long run.

Stage 2: Manufacturers select into markets and set prices for their goods in each market, taking transportation contracts (freight rates) as given; entry and exit is permitted in the long run.

Stage 3: Consumers in all markets fulfill demand, taking prices as given.

This timing implies that transportation firms act as Stackelberg leaders vis-à-vis manufacturers. That is, although manufacturers exercise market power in the markets for their goods (they are monopolistic competitors), they are unable to influence the freight rate. Transportation firms have a *strategic* advantage, represented by demand-for-service curves that have finite elasticity. However, manufacturers have an *information* advantage in that their marginal costs are private; only the distribution of these costs is public information. This results in two inefficiencies: (1) transportation firms must offer a common contract to all manufacturers based on aggregate statistics; (2) there is "double marginalization" in that both the manufacturers and the transportation firms mark up over marginal cost. We solve the model using backwards induction.

Stage 3: Consumers

Consumers in each country are identical. Utility is quasi-linear with quadratic sub-utility (QLQ),

$$U = q_0 + \alpha \int_{\Omega} q(i)^c di - (\gamma / 2) \int_{\Omega} (q(i)^c)^2 di - (\eta / 2) (\int_{\Omega} q(i)^c di)^2 , \tag{1}$$

where q_0 is individual consumption of the homogenous good, $q(i)^c$ is individual consumption of variety $i \in \Omega$ of the differentiated good and α, γ, η are parameters assumed greater than zero. Increases in α or decreases in η raise the consumer's preference for the differentiated good relative to the homogeneous good; increases in γ raise the degree of production differentiation. The budget constraint for an individual consumer is

$$p_0 q_0 + \int_{\Omega} p(i) q(i)^c di = p_0 \overline{q_0} + I , \tag{2}$$

where we assume a positive endowment of the homogeneous good for each individual. Maximizing (1) subject to (2) gives the individual demand for each variety of the differentiated good. With L consumers in each country, aggregate demand for variety i takes the form

$$q(i) = L q(i)^c = (\frac{L}{\gamma})(M - p(i)) , \tag{3}$$

where

$$M = \frac{\alpha\gamma + \eta N \overline{P}}{\gamma + \eta N} . \tag{4}$$

Note that the demand for any variety i is linear in own price, while the intercept (or choke price) is a function of two important market features. N is the number (or mass) of consumed varieties and $\overline{P}$ is their average price. A lower average price and/or a larger number of consumed varieties represent a more competitive market environment, shifting the demand curve down (lower intercept) and hence increasing the price elasticity of demand for any particular variety.

This demand function differs from the standard CES demand function in two important respects. First, CES preferences use a single parameter to capture the own-price elasticity of demand and the elasticity of substitution between varieties. Moreover, this same parameter then defines a constant markup over marginal costs for manufacturing firms in all markets. By contrast, the QLQ demand system permits distinct own-price and differential-price effects. As a result, variable markups characterize the pricing rules of manufacturers, reflecting the spatial distribution of consumers and competing firms.

The second important difference concerns income effects. The QLQ demand system is absent any income effects, unlike the typical CES formulation. This is a potential weakness in that it serves to divorce goods markets and trade flows from factor-market outcomes. As noted by Ottaviano et al. (2002), this gives the structure a strong 'partial equilibrium flavor.' Nevertheless, Ottaviano et al. (2002) and Baldwin et al. (2003) show that many of the most important results from the Helpman-Krugman class of trade models with differentiated goods and CES preferences carry over when using QLQ preferences. In this paper, we treat each country's L as an exogenous variable and use them to alter demand conditions in the comparative-statics analysis.

Stage 2: Manufacturers

Labor is the only factor of production and it is elastically supplied in a competitive market. The homogenous good is designated as the numeraire, produced under constant returns with unit costs, transported freely and traded in perfectly competitive markets. These assumptions imply equilibrium wages and prices $w_A = w_B = p_0^A = p_0^B = 1$.

Entry into the differentiated sector is subject to an entry cost F_m, after which the firm learns its marginal cost of production c. Productivity $(1/c)$ follows a Pareto distribution where

$$G(c) = (\frac{c}{c_m})^k \qquad c \in [0,\ c_m].$$

Note that the Pareto distribution collapses to the uniform distribution when $k = 1$, while $k > 1$ represents a distribution where low productivities (high costs) occur with greater frequency.

Monopolistic competition with a continuum of competitors has each firm developing and producing its own variety. As with CES preferences, firms neglect their own impact on aggregate market features (average price and number of firms). However, unlike firms facing CES demand curves, those aggregate variables do enter into the firms' pricing rules resulting in variable markups. This difference emerges because the price index enters the demand curve multiplicatively with CES preferences, but enters additively with QLQ preferences.

Markets are segmented—selling in the home market costs c per unit, while selling in the foreign market requires a purchase of transportation services. Specifically, manufacturers must surrender a fraction f of their output in order to ship the remainder to the foreign market. Profits for a firm with cost c in country B are thus[1]

$$\pi_B(c) = q_{BB}(p_{BB} - c) + q_{BA}((1 - f_{BA})p_{BA} - c) - F_m . \tag{5}$$

Maximizing (5) subject to (3) and (4) in each market results in domestic and foreign pricing equations for a firm with cost c,

$$p_{BB}(c) = (\frac{1}{2})(M_B + c) \tag{6}$$

$$p_{BA}(c) = (\frac{1}{2})(M_A + \tau_{BA}c) , \tag{7}$$

where

$$\tau_{BA} \equiv (1 - f)^{-1} .$$

Let c_D be the marginal cost of the firm that is just indifferent between producing and shutting down, and let c_X be the marginal cost of the firm that is just indifferent between selling only domestically and selling in both countries. In other worlds, firms with marginal costs $c < c_X$ are productive enough to compete and sell at home and abroad, earning positive (gross) profits in each market. Firms with marginal costs $c_X \le c \le c_D$ are productive enough to compete and sell in the home market, but not in the foreign market. Finally, firms with marginal costs $c_D < c < c_m$ are unable to compete in either market and so either shut down (in the short run) or exit (in the long run). Combining these definitions with (6) and (7) implies

[1] Results for firms in country A are isomorphic.

$$c_D^B = M_B \tag{8}$$

$$c_X^B = M_A \,/\, \tau_{BA} \tag{9}$$

and

$$c_D^A = c_X^B \tau_{BA} \tag{10}$$

$$c_D^B = c_X^A \tau_{AB}\,. \tag{11}$$

As shown in Melitz and Ottaviano (2005), all relevant manufacturing variables (prices, quantities, markups, revenues, and profits) can be written as functions of these cutoffs. In particular,

$$q_{BB}(c) = (\frac{L_B}{2\gamma})(c_D^B - c) \tag{12}$$

$$p_{BB}(c) = (\frac{1}{2})(c_D^B + c) \tag{13}$$

$$q_{BA}(c) = (\frac{L_A \tau_{BA}}{2\gamma})(c_X^B - c) \tag{14}$$

$$p_{BA}(c) = (\frac{\tau_{BA}}{2})(c_X^B + c)\,. \tag{15}$$

Note that, conditional on being able to compete in the home market, manufacturers with lower marginal costs sell larger quantities, charge lower prices, set higher markups and earn greater profits. Similarly, conditional on being able to compete in the foreign market, manufacturers with lower marginal costs sell larger quantities (export more), charger lower prices, set larger markups and earn greater profits. In addition, all manufacturers that serve both markets are effectively ‘dumping’—they absorb part of the transportation cost and so end up charging lower (net) prices on exports than on domestically sold goods.

The number of firms serving each market, the average prices and the cost cutoffs are all determined in equilibrium. Average prices in each country are a weighted average of the prices on domestically produced goods and imports. Thus

$$\overline{P}_B = (\frac{1}{N_B})(N_{BB}\int_0^{c_D^B} p_{BB}(c)dG(c) + N_{AB}\int_0^{c_X^A} p_{AB}(c)dG(c))\,. \tag{16}$$

The number of firms selling in a particular market (or the number of varieties available) is $N_B = N_{BB} + N_{AB}$. In a short-run equilibrium there is no entry or exit so each country has a fixed number of firms in operation, $\overline{N}_A, \overline{N}_B$. These firms select into markets based on each country's domestic and export cutoffs such that $N_{BB} = \overline{N}_B G(c_D^B)$ and $N_{BA} = \overline{N}_B G(c_X^B)$. As a result,

$$N_B = \overline{N}_B G(c_D^B) + \overline{N}_A G(c_X^A)\,. \tag{17}$$

The cutoffs are then determined by a combination of (16), (17) and (8) - (11):

$$\frac{\alpha - c_D^B}{(c_D^B)^{1+k}} = (\frac{\eta}{2\gamma(k+1)(c_m)^k})(\overline{N}_B + \overline{N}_A(1-f_{AB})^k)\,. \tag{18}$$

We can see that cost cutoffs are independent of the number of consumers in each country (L) but are sensitive to the number of firms in each market. Specifically, a rise in either the number of home or foreign firms increases competition in the home market resulting in a rising domestic cutoff. As a result, some firms that formerly sold in the domestic market shut down. Similarly, in the short run export cutoffs rise in tandem with domestic cutoffs with a rise in the number of firms. Note that the domestic cutoff is negatively related to the inward freight rate—the lower the cost of transporting goods from country A to country B, the easier it is for foreign manufacturers to penetrate the consumer market in country B, thus raising the domestic cutoff. The export cutoff, by contrast, is not affected by the inward freight rate; rather, it falls as the outward freight rate falls—the lower the cost of transporting goods from country B to country A, the easier it is for exporters to penetrate the consumer market in country A, thus lowering the export cutoff in country B.

Entry and exit in the long run drives manufacturing profits in both countries to zero. That is, firms paying the entry cost must earn zero expected profits in equilibrium. This condition takes the form:

$$\int_0^{c_D^B} \pi_{BB}(c)dG(c) + \int_0^{c_X^B} \pi_{BA}(c)dG(c) = F_m \tag{19}$$

Let N_A^E, N_B^E be the number of endogenous entrants in each country such that $N_B = N_B^E G(c_D^B) + N_A^E G(c_X^A)$. This equation, combined with (16) and the free-entry condition (19), gives an expression for the domestic cutoff in the long run:

$$c_D^B = \left(\frac{\phi\gamma}{L_B}\frac{(1-(1-f_{BA})^k)}{(1-(1-f_{AB})^k(1-f_{BA})^k)}\right)^{\frac{1}{k+2}} \tag{20}$$

where $\phi = 2(F_m)(c_m)^k(k+1)(k+2)$. Now an increase in the size of the domestic consumer market lowers the domestic cutoff because a larger consumer market attracts entrants. By contrast, the size of the foreign consumer market does not appear in the expression for the domestic cutoff, because the forces of entry offset any effects of a larger or smaller trade partner. A fall in the inward freight rate raises the domestic cutoff—greater competition from imports deters entry, while lowering the export cutoff—greater entry in the foreign country makes it tougher for exporters to penetrate the foreign market. A fall in the outward freight rate has just the opposite effects, as increased entry in the home industry makes it easier to export but harder to sell domestically.

Importantly, as noted by Melitz and Ottaviano (2005) and Helpman (?), this heterogeneous-firm model of trade shares many of the key features with the original model in Melitz (2003). There, CES preferences and constant markups shift firm competition into the factor markets, where entry and exit are governed by changing factor prices. Here, the lack of income effects, factor price equalization and perfectly elastic labor supplies make factor markets negligible. Instead, firms with variable markups compete in goods markets, where entry and exit are governed by goods prices. As we will see below, the transportation market is modeled here in much the same way—factor markets are effectively ignored, with all emphasis placed on the price of transportation services and its effects on manufacturers' decision making.

Stage 3: Transportation

Three key features motivate the transportation sector modeled here. First, transportation services are akin to other factors of production or intermediate inputs in many ways, but the most important difference is that only exported goods require this service. That is, not only does the price of transportation affect the volume of trade (the intensive margin), as shown above it also plays an important role in determining the pattern of trade (the extensive margin). Specifically, with heterogeneous firms, some will choose to export and some will not, and the price of transportation is an important factor in this decision as well as in the decision on how much to export.

The second key issue is that the international transportation industry is far from the competitive ideal. In his survey of the maritime economics literature, Lave (1999) documents that the provision of transportation services involves significant capital and administrative costs that are fixed with respect to output. In particular, modern shipping costs are only weakly correlated with distance travelled; average costs are generally falling in distance and volume shipped. This suggests the need to model transportation as an imperfectly competitive industry, one characterized by markups over marginal cost and incomplete pass-through.

Thirdly, transportation is a capital-intensive industry where capacity levels are crucial to the provision of service. Expanding capacity requires substantial long-term investment, and it is unlikely that the world fleet can grow and change as quickly as world demand. This model distinguishes between the allocation of existing capacity among various routes and the construction of new capacity. Following capacity-constrained models presented in Maggi (1996) and Kreps and Scheinkman (1983), the former represents the short-run response by the transportation industry to changes in demand; the latter represents the eventual long-run response to such changes.

The costs facing transportation firms are here treated very simply to highlight the above issues and in order to nest the familiar iceberg assumption. There are three distinct costs. First, firms wishing to invest in new capacity must pay s_0 for each unit of capacity built. Capacity-building is a long-run proposition; in the short run, this cost is treated as fixed. Second, the cost of transporting quantity Q from country B to country A is given by the function $S(Q_{BA}, d_{BA})$, where the marginal cost of transportation is s. We assume s is increasing in distance, but in the simple two-country model presented here, distance is the same in both directions $s = s_{AB} = s_{BA}$. The model is flexible enough, however, to incorporate different distances and other features that may lead to different marginal costs. Finally, transportation firms wishing to reallocate their existing capacity across routes can do so at cost θ per unit moved. This is meant to capture variously the physical costs of moving vehicles and equipment, the price paid to supplement capacity from local sources and/or the congestion costs of increased traffic flow.

Demand for transportation services originates in the trade model. Recall the timing and information assumptions of the model: transportation firms face downward sloping demand curves, but c is private information for each manufacturer. Hence, the transportation firms set a single freight rate f for each route, based on the aggregate demand for transportation services by all exporting firms. That demand can be written as the number of exporting firms, N_{BA}, times the expected value of the quantity of exports, conditional on a firm being an exporter. The simplified expression is

$$Q_{BA}(f_{BA}) = Z_{BA}(1 - f_{BA})^k, \qquad (21)$$

where the coefficient is given by

$$Z_{BA} = \frac{L_A c_D^A N_{BA}}{2\gamma(k+1)}. \qquad (22)$$

It will sometimes be convenient to use the inverse demand form given by

$$f_{BA}(Q_{BA}) = 1 - (\frac{Q_{BA}}{Z_{BA}})^{\frac{1}{k}}. \tag{23}$$

CASE 1: Perfect Competition

This case is straightforward—if we assume free entry, costless capacity and marginal-cost pricing, then we would expect the freight rate on each route to equal the marginal cost $f = s$. This result is tantamount to employing the iceberg assumption, where s is the relevant 'melt factor' for each route. Note this does not imply that freight rates will always be identical, only that the rates will differ only insofar as the cost characteristics of the routes (such as distance) differ. This case does provide an efficiency benchmark—once we introduce an imperfectly competitive transportation industry, double marginalization will reduce the value of trade.[2]

CASE 2: Monopoly

Consider a single transportation firm that serves both routes, *BA* and *AB*. In the short run, the transportation firm takes the initial level of capacity assigned to each route as given, X_{BA}, X_{AB}. This firm does not face competitive pressure, but it may want to reallocate some of its capacity in response to changes in demand. The short-run profit function takes the form:

[2] This would be true even if the transportation firms had perfect information about manufacturers' marginal costs.

$$\begin{aligned}\pi_s &= (f_{BA}(X_{BA}+\varepsilon))(X_{BA}+\varepsilon)-(s)(X_{BA}+\varepsilon)\\ &+(f_{AB}(X_{AB}-\varepsilon))(X_{AB}-\varepsilon)-(s)(X_{AB}-\varepsilon)-\theta\varepsilon\mathrm{I}(\varepsilon\geq 0)+\theta\varepsilon\mathrm{I}(\varepsilon\leq 0)-F_s\end{aligned} \tag{24}$$

The transportation firm chooses ε to maximize this function, where a positive value represents a movement of some capacity to the BA route, a negative value represents a movement of some capacity to the AB route and zero indicates no movement. The indicator functions ensure that the movement cost is paid in either direction but zeroes out when no movement is chosen. The first order condition is

$$\theta\mathrm{I}(\varepsilon\geq 0)-\theta\mathrm{I}(\varepsilon\leq 0)=\frac{(1+k)(X_{AB}-\varepsilon)^{\frac{1}{k}}}{k(Z_{AB})^{\frac{1}{k}}}-\frac{(1+k)(X_{BA}+\varepsilon)^{\frac{1}{k}}}{k(Z_{BA})^{\frac{1}{k}}} \tag{25}$$

We can interpret this condition on the three relevant rages for ε. First, consider the proposed solution $\varepsilon=0$. Using (23) and (25) we can see that this is optimal only when $f_{AB}=f_{BA}$. That is, when capacity is already allocated such that the freight rate on each route is equalized, then there is no need to adjust capacity. This will occur when demand conditions along each route are the same and the initial allocation along each route is the same.

Now consider a proposed solution in the range $\varepsilon>0$. Again using (23) and (25), we can see that this will only be optimal when

$$\theta\frac{k}{k+1}=f_{BA}-f_{AB}. \tag{26}$$

That is, when demand increases along the BA route, it will put upward pressure on the freight rate for a given capacity. Similarly, when $\varepsilon<0$, demand is increasing along the AB route, putting upward pressure on that rate. In this case

$$\theta\frac{k}{k+1}=f_{AB}-f_{BA}. \tag{27}$$

The transportation firm will find it optimal to move some of its capacity over from the low-demand to the high-demand route, until the difference between the two rates is equal to a fraction of the moving cost, where the fraction is determined by the shape of the distribution of the manufacturers' marginal costs. Specifically, if manufacturers are distributed uniformly $(k = 1)$, then the rates will adjust until they differ by exactly half the moving cost. If manufacturers are skewed towards low costs $(k > 0)$, then the rate gap will increase accordingly. The important point is that, in the face of a demand shift on one route, short-run capacity constraints lead to increases in freight rates on both routes, albeit by different amounts.

In the long run, the transportation firm can invest in new capacity along each route. This amounts to choosing X_{AB}, X_{BA} to maximize profits. The long-run profit function is

$$\pi_s = (f_{BA}(X_{BA}))(X_{BA}) - (s + s_0)(X_{BA}) + (f_{AB}(X_{AB}))(X_{AB}) - (s + s_0)(X_{AB}). \tag{28}$$

The optimal capacities satisfy

$$X^{BA} = (Z^{BA})(1 - s - s_0)^k (\frac{k}{1+k})^k \tag{29}$$

$$X^{AB} = (Z^{AB})(1 - s - s_0)^k (\frac{k}{1+k})^k, \tag{30}$$

and imply freight rates

$$f_{BA} = f_{AB} = \frac{1 + k(s + s_0)}{1+k}. \tag{31}$$

CASE 3: Duopoly
(to be completed…)