Potential Effects of Technological Advances in Transportation on the Trade of Food Products between the U.S. and Latin America

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Price differentials between spatially separated trading regions are substantial due to artificial trade restrictions and natural trade barriers such as transportation costs. Transportation cost greatly affects trade of agricultural products, especially high-value/time-sensitive and perishable (HV/TS & P) commodities, due to their high transportation cost.

Given the importance of transportation costs as a natural trade barrier, a large body of literature exists on applied research that has studied the effect of transportation rate-structure changes in inter- and intra-regional trade. Most studies have modeled changes in transportation cost structure from the opposite focus of this study--that is, from an increasing rather than decreasing transportation cost structure. The commonly used method in this type of research is Spatial Equilibrium Models (SEM), which are useful for analyzing price relationships and the resulting trading patterns between two or more regions due to changes in transportation cost structure or any other artificial trade barrier.

This paper implements a SEM to simulate the effect of reductions in transportation cost due to technological advances by implementing fast-displacement-vessel routes between the Southern U.S. and Latin American ports.

Fast-displacement Vessels

According to Farris and Welch (1998), fast-ship technology for cargo purposes is not a new concept; its history goes back to the early 1970s. In 1971 Sea Land Company built eight vessels (the SL-7s) with a speed of 35 knots to provide service across the Atlantic. Fast vessels for cargo offer the advantage of being a cost-effective alternative for developing nations, compared to airfreight and regular freight vessels, over a given range of commodities and trade distances. The advantage over airfreight is lower transportation costs; with regular vessels the advantage is technical, based on the fact that the new vessels are faster and have shallower drafts, which allow them greater access to smaller ocean and river ports, characteristics of many developing countries. These vessels also have a higher trip frequency per year than do conventional vessels, allowing them to increase the number of cargo units moved per year at a potentially higher price.

The latest advances in vessel construction are aimed at making slender high-performance vessels to reduce drag. In propulsion, the main focus has been on heavy energy-saving diesel engines. Recently the focus has shifted to high-performance gas turbines, in order to make vessels lighter. Gas turbines are more expensive to operate, but as the need for horsepower increases, gas turbines are considered more advantageous.

The implementation of fast-vessel transportation is likely to reduce transportation costs within given distances and ranges of commodities. This cost reduction is expected to increase the quantity of HV/TS & P traded by reducing import prices and increasing quantity demand in importing regions, and increasing export prices and therefore quantities supplied in the exporting region. As result, there is an expected welfare gain to society, measured by an increase in consumer and producer surplus in the regions involved in trade.

The benefit derived from implementing a new transportation technology that reduces cost and increases trade can be divided in four basic categories: cost-reduction benefits, measured by the reduction in resources required to move the commodities with the new technology; shift-of-mode benefits, the gains resulting from the reduction in cost required to move commodities with the new technology, relative; shift of origin to destination benefits, measures the increase in commodity movements originating

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or terminating at a different location with the new technology, and new-movement benefits, which measure the increase in the amount of current and new commodities flow that occurs only with the implementation of the new technology.

The Model

The spatial-equilibrium model implemented in this study is static rather than dynamic, involves partial equilibrium, and makes use of quadratic programming technique. In conformity with most SEM empirical applications, this model assumes homogeneous products; perfect competition in supply and demand of commodities and in transportation services; and that prices and quantities are determined along the demand and supply functions, which remain unchanged in the basic model.

The model implemented in this paper was developed according to Takayama and Judge (1964) and draws from the experience of other studies. This model uses price formulation, in which the decision variables are prices and interregional quantity flows. The model incorporates export-supply equations at Southeast U.S. export districts and import demand equations in foreign importing regions. Exporting districts are linked to importing regions through transportation activities

Let $I = 8$ be the number of trading regions, $i = 4$ be the number of exporting regions, $j = 4$ be the number of importing regions, and $n = 2$ be the number of commodities traded between the regions. The specific notation for the conceptual model is $W(n_{ij}) = NSP$ = Net Social Payoff, or the social-welfare function to be maximized; ES_{ni} = excess supply function for commodity n exported from region i; ED_{nj} = excess demand function for commodity n imported in region j; $P^s_{ni} = P_x$ = export price of commodity n in export region i; $P^d_{nj} = P_m$ = import price of commodity n in region j; T_{ij} = transportation cost between regions i j; It_j = ad-valorem import tariffs in the importing region j; and $X_{nij} = X_{nji}$ = quantity of commodity n exported from region i to j and vice versa. The general notation of the model implemented for this study is

$$(1)\quad W = \sum_{i=1}^{4}\int_{0}^{p_{ni}} ES_{ni} \times \partial P^s_{ni} + \sum_{j=1}^{4}\int_{p_{nj}}^{p_{ni}} ED_{nj} \times \partial P_{nj}^{\ d} - \sum_{i=1}^{4}\sum_{j=1}^{4}(T_{ij} + It_j) \times X_{ij}$$

Subject to

$$(2)\quad ES_{ni} \geq \sum_{j=1}^{4} X_{nji}\ ,$$

$$(3)\quad ED_{nj} \leq \sum_{i=1}^{4} X_{nij}\ ,$$

$$(4)\quad \sum_{j=1}^{4} ES_{ni} = \sum_{j=1}^{4} ED_{nj}\ ,$$

$$(5)\quad P^d_{nj} - P^s_{ni} \leq T_{ij} + It_j\ ,$$

$$(6)\quad ES_{ni} \geq 0,\ P^s_{ni} \geq 0,\ ED_{nj} \geq 0,\ X_{nij} \geq 0.$$

Equation (1) represents the Net Social Payoff function net of transportation cost plus ad-valorem import tariffs, equations (2) and (3) represent the trade-flow constraints, and equation (4) represents non-negativity constraints. Equation (5) is a constraint which indicates that the price differential between two regions cannot exceed transfer costs; in this case, transfer cost equals transportation cost plus import tariffs. Equation (6) indicates that all of the decision variables must be positive. Demand and supply equations are linear functions of own prices:

$$(7)\quad ES_{ni} = \alpha_0 + \alpha_1 P^s_{ni} \quad \text{and} \quad ED_{nj} = \beta_0 + \beta_1 P^d_{nj}$$

where α_0 and β_0 = intercepts of the export supply and import demand equations, respectively, and α_1 and β_1 = slopes of the export supply and import demand equations, respectively.

Excess Supply and Demand Equations

To define the export supply and import demand equations, the respective elasticities must be estimated. Export and import elasticity were derived using domestic price elasticity of supply and demand for the respective regions involved in the analysis, following Houck (1986) and Koo and Larson (1985):

$$(8)\quad \varepsilon_{xs} = e_{si}\frac{Q_{si}}{Q_{xi}} + |e_{di}|\frac{Q_{di}}{Q_{xi}} \quad \text{and} \quad \varepsilon_{md} = e_{dj}\frac{Q_{dj}}{Q_{mj}} + e_{sj}\frac{Q_{sj}}{Q_{mj}}$$

where ε_{xs} = excess or export supply elasticity and ε_{md} = excess or import demand elasticity. e_s = domestic supply elasticity, e_d = domestic-demand elasticity, Q_s = domestic quantity supplied, Q_d = domestic quantity demanded, in exporting i and importing j regions, Q_{xi} = quantity exported from exporting region, and Q_{mj} = quantity imported in importing region. Domestic elasticity for exporting and importing regions were obtained from Sullivan, Waino, and Roningen (1991). The estimated export supply elasticity is assumed to be the same for the 4 export districts in the U.S southeast region.

Domestic quantities supplied, demanded, and consumed in the exporting and importing regions are three-year averages (1997–2000) of production, stock changes, and consumption obtained from FAO (2003). Quantities supplied for each of the four Southeast U.S. districts and imported into the Latin America and Caribbean regions are three-year averages of the data obtained from the Bureau of Census (1997, 1998, 2000). The data was extracted by two-digit commodity codes for beef & veal and for poultry. The extracted data were air exports from the following U.S. customs districts: Miami, FL; New Orleans, LA; Charleston, NC/Savannah, GA; and Houston/Galveston, TX. Data for each of these districts were separated further into exports from each of these districts to import ports in four Latin America regions: Puerto Veracruz, Mexico; Puerto Cortes, Honduras; Caracas, Venezuela; and Port au Prince, Haiti.

Based on the elasticity of excess demand and supply, the linear export supply and import demand functions, as specified in equation (7), were estimated using the approach demonstrated by Koo and Larson (1985). The intercepts and slopes can be derived as follows:

(9) $\alpha_1 = \varepsilon_{xs} \dfrac{Q_x}{P_x}$ **and** $\alpha_0 = Q_x - \alpha_1 P_x$

(10) $\beta_1 = \varepsilon_{md} \dfrac{Q_m}{P_m}$ **and** $\beta_0 = Q_m - \beta_1 P_m$

where, ε_{xs}, ε_{md}, Q_m, and Q_x are as defined above, while P_x and P_m are export and import prices at exporting and importing regions, respectively. Export prices are simply the ratio of the air export values to the export quantity for each of the U.S. districts. Import prices at each of the import regions were estimated by adding transportation cost (T_{ij}) to export prices and import tariffs (It_j) at each of the importing regions. Import tariffs are calculated as a product of export price times average ad-valorem regional import-tariff rates ($\overline{t}_j$):

(11) $P_x = Exp\ Value \div Exp\ Quantity$

(12) $P_m = P_x + T_{ij} + It_j$

(13) $It_j = P_x \text{ x } \overline{t}_j$

The import-tariff rates used are the median of the regional tariffs for poultry and beef, obtained from ERS/USDA(2001). Median import-tariff rates were chosen because they are considered to be a more representative measure for comparing the overall tariff schedule of each region, since they are less sensitive to a few extremely high and low rates.

Airfreight-transportation cost was calculated as an average of the charges per kilogram between the different regions considered in this study, published by three airlines and a cargo forwarder: Northwest Airlines Cargo (2001), United Cargo (2001), Delta Air Lines Cargo (2001), and APX Cargo (2001). Fast-vessel transportation cost was estimated according to Fuentes, Couvillion, and Allen (2003). Based on the cost estimation and a fast-vessel commercial and financial viability analysis, it was determined that the catamaran fast ship or a vessel with similar characteristics and cost structure (44 FEU capacity and a service speed of up to 40 knots) would be the most appropriate to implement routes between the regions considered in this study.

Empirical Results

This study includes one base model and three alternative simulations for transportation-rate reductions. The base model is implemented using three-year average airfreight imports and exports of beef and poultry, and transportation rates. The base model was then use as a benchmark against which the results from the other alternatives simulations were compared. The alternative simulations were implemented by reducing air transportation rates, assuming a reduction equivalent to a given percentage of the cargo being moved by fast vessel and applying the estimated fast-vessel rates to that percentage in three different scenarios. The analysis presented in this study relies on the major assumption that products moved by airfreight and fast vessels are facing the same demand and supply functions. This assumption is introduced in order to simplify the analysis, given that such functions for fast vessels are unknown and cannot be estimated at this time.

Model Validation

The model was validated according to McCarl and Spreen (1997). Results show that the base model was able to replicate closely the original data for quantities and prices. The model seems to predict better for beef than for poultry, reflected in the percentage of prediction of export and import quantities and prices. Specific regional quantities of most beef and veal exports and imports were slightly overestimated. Most poultry quantities are overestimated in a larger proportion than for beef. In general, the base-model results are congruent with actual data.

Specific beef and veal quantity flows between different Southeast U.S. districts and Latin American and Caribbean ports are mostly underestimated. The model was not able to simulate effectively low current flows, since they are associated with extremely low and high estimations. In terms of prices, the base model closely replicates most import and export prices for beef and veal; the highest export price overestimation was 1.2%, for New Orleans. Poultry prices are not replicated as well as in beef, and they are underestimated by 13.2% for Miami export prices and by 11.1% for Central America import prices.

Predictive performance was tested using the Theil "U" inequality coefficient, which is a non-parametric goodness-of-fit test, commonly use in mathematical programming (Leuthold 1975). This test measures the prediction or forecasting accuracy of a model. A coefficient close to zero indicates an almost perfect prediction, while a value near 1 corresponds to near-perfect inequality or negative proportionality between the actual and predictive values. In this study, this coefficient corroborates the findings of the model predictions for quantities, prices, and flows.

Conclusions, Implications, and Limitations

The reduction in transportation cost resulted from the introduction of fast-ship transportation, which is assumed to be competitive with airfreight and is expected to have an impact on producer and consumer surplus through an increase in total interregional commodity flows between the U.S. and Latin America. This expected trade increase is the result of a reduction in import prices and an increase in export prices for high-value and perishable commodities relative to the existing airfreight-transportation cost structure.

Results from the model show, as expected, that the reduction in transportation cost will have a positive impact on the flow of high-value and perishable commodities, increasing trade up to 6.1% for beef and 39.6% for poultry when 50% of the total commodity traded is moved by fast vessels (Table 1). Results also show that in the case of Central America and the Caribbean, contrary to expectations, imported quantities decrease as transportation costs are reduced, because import prices increase due to the high tariff rates imposed in these regions. This implies that in order for the countries in these regions to benefits from the introduction of fast-ship transportation technology and the consequent reduction in transportation cost, these countries will have to reduce import-tariff rates to a point where the reduction in transportation costs is equal to or greater than the increase in import taxes, in order to reduce import prices and increase import quantities and consumption.

According to the Bureau of Census (2000) the quantity traded by air between the Southeast U.S. region, Latin America, and the Caribbean amounted to 792.3 thousand MT. If this increases by as much as 39.6% (according to the simulation for poultry), the total quantity of high-value and perishable commodities traded will increase to a total of 1,101.3 thousand MT**.** Since air transportation alone is not capable of absorbing this increase, given its high cost and the limited capacity of the Latin America region, the introduction of fast-vessel routes would be advantageous. If fast vessels absorb 15% of this total, it will represent about 165.2 thousand MT. If we assume further that this cargo is distributed equally throughout the year, and assume 191 vessel trips per year with a capacity of approximately 638 MT per trip (for a high-speed catamaran with 80% load factor), at least two vessels will be necessary to move this cargo. If fast vessels absorbed 50% of the total, then at least five vessels would be necessary to move this cargo.

Based on the whole set of assumptions used in the development of this model, the introduction of a fast-vessel service can increase social welfare by increasing the amount of goods traded between the regions involved in the analysis, benefiting producers and consumers in these regions. Even though these results seem promising, we must be cautious about these conclusions, given the limitations of this analysis. Some of these limitations are inherited from the modeling process and the cost analysis, but more important are limitations in data with regard to flows and the cost of the products that must rely on a technology that is still being developed and not yet implemented. These limitations, together with the uncertainties associated with the estimation of demand and supply for actual and new products resulting from the introduction of this technology, suggest that it would be reasonable to be cautious about such conclusions.

Given that fast-ship service does not exist and that its implementation will take a few years, any analysis done in the near future will have to rely on data and information available from the other two extremes of the transportation-service spectrum--that is, regular ocean freight and airfreight--with the knowledge that the new technology cost and other parameters such as elasticity will be somewhere between the parameters of the observed two extremes; any pertinent analysis can be based on these estimates until more reliable data and information for this technology become available.

In spite of the limitations and constraints stated previously, the model developed in this study provides a comprehensive basis for studying the effect of transportation-cost reduction on the flow of high-value and perishable commodities between the regions involved in the analysis. These results can provide perspective for the transportation industry and governments as they consider the implications of trade globalization and any other policy reforms that involve the expansion of trade.

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Table 1. Beef and Poultry Trade-Simulation Results with Transportation-Rate Reductions Due to the Introduction of Fast-Ship Transportation between the Southeastern U.S., Latin American, and Caribbean Regions, Relative to Air Trade.

	Beef							Poultry						
Quantity flow (MT)	Base Model	90%-10%	% Change	70%-30%	% Change	50%-50%	% Change	Base Model	90%-10%	% Change	70%-30%	% Change	50%-50%	% Change
Miami-Mexico	259.73	264.03	1.7%	272.66	5.0%	281.28	8.3%	39.99	0.00	-98.9%	0.00	-100.0%	0.00	-100.0%
New Oeleans-Mexico	0.00	0.00		0.00		0.00		-	-	-	-	-	-	-
Houston-Mexico	50.78	51.80	2.0%	53.85	6.0%	55.89	10.1%	91.46	137.40	56.3%	149.32	63.3%	161.19	76.2%
Savannah-C. America	0.00	0.00		0.00		0.00		1.80	0.00		0.00		3.35	
Miami-C. America	29.87	29.62	-0.8%	29.11	-2.5%	28.60	-4.2%	66.22	69.44	5.6%	72.29	9.2%	71.82	8.5%
New Orleans-C. America	2.33	2.35	1.1%	2.41		2.48	6.5%	-	-	-	-	-	-	-
Savannah-S. America	0.00	0.00		0.00		0.00		59.96	33.39		56.49		76.69	
Miami-S. America	19.08	19.61	2.8%	20.68	8.4%	21.75	14.0%	39.40	90.62	164.6%	116.76	196.4%	146.02	270.6%
Houston-S. America	8.88	8.88	0.0%	8.88	0.0%	8.88	0.0%	55.08	17.58	-63.0%	22.47	-59.2%	27.61	-49.9%
Savannah-Caribbean.	4.28	4.32	1.1%	4.42	3.3%	4.51	5.4%	68.05	107.25	56.0%	105.74	55.4%	103.96	52.8%
Miami-Caribbean.	40.63	40.02	-1.5%	38.82	-4.5%	37.61	-7.4%	4.46	4.46	0.0%	4.46	0.0%	4.46	0.0%
Import Price ($/MT) at														

Table 1. Beef and Poultry Trade-Simulation Results with Transportation-Rate Reductions Due to the Introduction of Fast-Ship Transportation between the Southeastern U.S., Latin American, and Caribbean Regions, Relative to Air Trade. (Continued)

Mexico	5127.66	5112.08	-0.3%	5080.91	-0.9%	5049.73	-1.5%	3024.86	2970.55	-3.6%	2861.80	-5.4%	2753.46	-9.0%
Central America.	6128.53	6141.97	0.22%	6168.82	0.7%	6195.67	1.1%	3636.80	3614.41	-1.2%	3569.81	-1.8%	3524.64	-3.1%
South America	5490.21	5473.31	-0.3%	5439.49	-0.9%	5405.66	-1.5%	3491.07	3440.90	-2.9%	3340.70	-4.3%	3240.04	-7.2%
Caribbean	6902.13	6927.96	0.4%	6979.61	1.1%	7031.25	1.9%	4088.52	4060.98	-1.4%	4005.70	-2.0%	3951.04	-3.4%
Export Price ($/MT) at														
Savannah/ Charleston	3082.41	3130.22	1.6%	3225.84	4.7%	3321.46	7.8%	1601.56	1621.28	2.4%	1660.62	3.7%	1700.29	6.2%
Miami	3094.39	3144.80	1.6%	3245.59	4.9%	3346.38	8.1%	1613.55	1639.31	3.2%	1690.94	4.8%	1742.22	8.0%
New Orleans	3080.59	3131.16	1.6%	3247.46	5.4%	3363.75	9.2%	-	-	-	-	-	-	-
Houston/Galveston	2973.00	3045.49	2.4%	3190.44	7.3%	3335.40	12.2%	1597.76	1611.70	1.7%	1639.47	2.6%	1667.56	4.4%
Export Quantity (MT) at														
Savannah/ Charleston	4.28	4.32	1.1%	4.42	3.3%	4.51	5.4%	129.82	140.64	16.6%	162.24	25.0%	184.01	41.7%
Miami	349.30	353.29	1.1%	361.26	3.4%	369.24	5.7%	150.06	164.53	19.4%	193.51	29.0%	222.30	48.1%
New Orleans	2.33	2.35	1.2%	2.41	3.8%	2.48	6.5%	-	-	-	-	-	-	-
Houston/G	59.66	60.68	1.7%	62.72	5.1%	64.77	8.6%	146.55	154.98	11.4%	171.79	17.2%	188.80	28.8%
Import Quantity (MT) at														
Mexico	310.51	315.84	1.7%	326.50	5.2%	337.17	8.6%	131.45	137.40	9.1%	149.32	13.6%	161.19	22.6%
Central America	32.19	31.97	-0.7%	31.52	-2.1%	31.07	-3.5%	68.01	69.44	4.2%	72.29	6.3%	75.18	10.5%
South America	27.96	28.49	1.9%	29.56	5.7%	30.63	9.6%	99.36	124.02	49.5%	173.25	74.4%	222.71	124.1%
Caribbean	44.90	44.35	-1.2%	43.23	-3.7%	42.12	-6.2%	127.60	129.29	2.7%	132.68	4.0%	136.03	6.6%
Total Exports/ Imports	415.56	420.64	1.2%	430.82	3.7%	441.00	6.1%	426.43	460.15	15.8%	527.54	23.7%	595.11	39.6%

*Transportation-rate reduction is induced by the introduction of fast vessels, assuming that these vessels transport a given percentage of the cargo, i.e. in the 90%-10% scenario, 10% of the cargo is transported by fast vessels.