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The Panama Canal: How Important to U.S. Grain/Oilseed Exports?

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Abstract

The Panama Canal will be transferred to the Republic of Panama on December 31, 1999. Some believe the Panamanians will not follow the break-even management philosophy of the U.S. and will attempt to maximize toll revenues. Other critics hold that Canal management and maintenance will suffer from corruption and nepotism. They believe political patronage and inflated payrolls will drain resources from the Canal, and this will lead to inadequate maintenance which eventually will make the Canal virtually inoperable. Spatial models of the international corn and soybean sectors are used to evaluate the strategic role played by the Panama Canal for U.S. corn and soybean exports. Grain and oilseeds are the leading commodities transiting the Canal: about 44 percent of U.S. corn and soybeans move via this transport artery. Two scenarios are examined. The first scenario determines the effects of increasing Canal tolls while the second examines the effect of Canal closure. Increasing tolls reduce exports via U.S. Gulf ports, increase exports via U.S. Pacific northwest ports, reduce quantities transiting the Canal and increase flows to east Asia via Africa's Cape of Good Hope. In addition, the U.S.'s role in Asia's corn and soybean markets declines while Europe and north Africa become increasingly important markets for U.S. producers. Total corn and soybean exports of the U.S. decline no more than 2 percent. Analysis suggests a revenue-maximizing Canal operator could substantially increase revenues by adjusting tolls upward by \$2 per ton of cargo on corn-laden vessels and \$1 per ton on soybean-laden ships. This would lower U.S. producer annual corn and soybean revenues about \$160 million. Closing the Canal has a similar effect on flows and trading partners as higher tolls. If the Canal were closed, revenues of U.S. corn and soybean producers are projected to decline \$303 million per year.

The Panama Canal: How Important to U.S. Grain/Oilseed Exports?

The Panama Canal Treaty of 1977 transfers the administration and operation of the Panama Canal to the Republic of Panama on December 31, 1999. The Treaty includes a provision that has provided for the transition of Canal responsibilities to the Panamanians. Most indicate the transition process has been a success, regardless shipping and agricultural interests believe problems may exist when the Panamanians assume control (Fabey; Wylie; *The Economist*). The purpose of this study is to evaluate the strategic role of the Panama Canal in U.S. grain/oilseed exports.

Grain and soybeans are the leading commodities transiting the Canal. Historically, these commodities have comprised about 20 percent of all Canal tonnage. Petroleum and petroleum products have ranked second with about a 16 percent share of total tonnage while containerized freight followed with a 13 percent share. The ores and metals group have made up about 6 percent of tonnage, while the coal and coke, lumber and products, and chemical and petrochemical groups each comprise from 5 to 6 percent of all tonnage (Panama Canal Commission, Annual Report)

Annual grain/oilseed traffic transiting the Canal during the 1992-1998 period ranged from 35.9 mmt to 48.4 mmt. Half of the grain/oilseed traffic was corn followed by soybeans (22%), wheat (17%) and sorghum (5%). Further, except for wheat, virtually all of these commodities transited the Canal from the Atlantic to Pacific Ocean. About two-thirds of the wheat traffic flowed from the Atlantic to Pacific Oceans in 1992-1998 with the remaining passing from the Pacific to Atlantic Ocean (Panama Canal Commission, Annual Reports).

The United States is the principal source of the Panama Canal's grain and soybean traffic. Nearly 98 percent of the Canal's corn traffic originates at U.S. ports (primarily Gulf ports) and passes from the Atlantic to Pacific Ocean for destinations in Asia, and the west coasts of South and Latin America. In addition, almost all of the Canal's soybean and sorghum traffic (nearly 99 %) originates at U.S. Gulf ports and traverses the Canal for destinations in Asia, Oceania and the west coasts of South and Latin America. In contrast, about 90 percent of the wheat traversing the Canal from the Atlantic to Pacific Ocean originated at U.S. ports while the U.S. share passing from the Pacific to Atlantic Ocean was about one-third.

Based on historic U.S. exports, it is estimated that about 44 percent of U.S. corn and soybean exports transit the Canal as do about one-third of sorghum exports and 16 percent of wheat exports. Primary destinations for U.S. grain/oilseeds transiting the Canal are Japan, South Korea and Taiwan in Asia, and Chile, Peru, Ecuador and Columbia on west coast of South America and Mexico in Central America.

Panama Canal: Issues and Predictions

The ability of the Panamanians to successfully administer and operate the Canal *ex post* their take-over is debated. Panama Canal tolls account for about 9 percent of Panama's gross domestic product, however, service-oriented industries employ thousands, thus the Canal's contribution to the economy far exceeds Canal toll revenues (Falcoff). Some Panamanians believe the Canal will be a bonanza that increases government revenues by 15 to 20 percent. They argue the Canal should be managed to increase government revenues and not operated on a break-even basis as had been done by the United States. Some suggest, however, that maritime economics and not political pressure was the reason for the break-even philosophy followed by

the United States. A study prior to ratification hearings in 1977-1978 suggested traffic levels would decline with toll increases and revenues would remain almost unchanged (Falcoff). It was argued that many Canal users have alternatives that involve shipping in larger vessels via different ocean routes (Africa's Cape of Good Hope). And, in some cases, international trading partners may be altered as tolls increase, thus negating the need to ship via the Canal. A more recent study by the Panama Canal Commission showed most bulk trades, excluding grain, are sensitive to rate hikes (www.panamet.com/pancanal/proposal/impact.htm). However, the extent the toll rate might be increased by a revenue-maximizing operator is unknown. This is particularly a concern for grain, where previous research suggested toll increases create small diversions.

Critics indicate Canal management and maintenance will suffer from corruption and nepotism when the Canal is administered by the Panamanians. Although this concern may be real, the Panamanian government has taken steps to create a public body, the Panama Canal Authority, that is to monitor and advise with respect to Canal operations and management. Although the provisions establishing the Panama Canal Authority seem adequate to circumvent corruption, critics argue that inflated payrolls, noncompetitive acquisition of goods and services, and political patronage will drain resources from the Canal. And, this will lead to inadequate maintenance that will eventually make the Canal an inefficient and undesirable choice for the international shipping community.

Study Objectives and Procedure

The primary objective of this study is to evaluate the strategic role played by the Panama Canal in U.S. corn and soybean exports, a transportation artery for over 40 percent of

these commodities respective exports. Two scenarios are examined. The first scenario attempts to evaluate the effect of increasing Panama Canal toll rates while the second examines the effect of Canal closure. The effects of these happenings on U.S. corn and soybean flow patterns, export levels and producer revenues are evaluated.

Analysis is accomplished with spatial, intertemporal models of the international corn and soybean sectors. The effects of higher Panama Canal toll rates are evaluated by adjusting ship rates on those links that traverse the Panama Canal and incorporating alternative ship routings and rates into the model. Affected ship rates include those that link U.S. Gulf and Atlantic ports with foreign import demand regions located on the west coast of South America, west coast of Central America, and east and southeast Asia. The effects of Canal closure are similarly evaluated by closing these transport links. To successfully evaluate the effects of higher Panama Canal tolls and Canal closure, alternative routes and associated ship rates were estimated and included in the models.

Base models representative of the international corn and soybean sectors during the 1990s were initially estimated. To evaluate the effects of higher Canal tolls and Canal closure, parameters in the base models were adjusted to reflect these two scenarios and the models subsequently solved. Those solutions are contrasted with the base model solutions to determine the effects of higher Canal toll rates and Canal closure on U.S. flow patterns, export levels and producer revenues.

Models and Data

Spatial Equilibrium Models

The corn and soybean models used to accomplish research objectives are spatial, intertemporal equilibrium models that include domestic and international corn and soybean sectors. The quadratic programming models generate interregional trade flows and prices that result from maximizing producer plus consumer surplus minus grain handling, storage and transportation costs (Samuelson). The models include considerable detail on regional excess demands and supplies, and transportation, storage and grain handling costs in the United States and Mexico.

The following is a mathematical representation of the corn and soybean models under the assumption of linear excess demand and supply relationships. Equation 1 is the objective function which is maximized subject to constraints 2 through 13. See Table 1 for definition of subscripts, parameters and variables included in the following equations:

$$(1) \text{ Maximize } Z = \left\{ \sum_q \right. \\ \left. \{ - \sum_i (\alpha_{iq} + 0.5 \beta_{iq} S_{iq}) S_{iq} - \sum_r (\alpha_{iq} + 0.5 \beta_{rq} S_{rq}) S_{rq} \right. \\ \left. - \sum_r (\alpha_{rq} + 0.5 \beta_{rq} S_{rq}) S_{rq} \right. \\ \left. + \sum_j (\alpha_{jq} - 0.5 \beta_{jq} D_{jq}) D_{jq} + \sum_d (\alpha_{dq} - 0.5 \beta_{dq} D_{dq}) D_{dq} \right.$$

$$\begin{aligned}
& + \sum_h (\alpha_{hq} - 0.5 \beta_{hq} D_{hq}) D_{hq} \} \\
& - \{ \sum_m (\sum_i (\sum_j C_{ijm} T_{ijqm}) + \sum_b C_{ibm} T_{ibqm}) + \sum_p C_{ipm} T_{ipqm} \} \\
& + \sum_r \sum_h (C_{rhm} T_{rhqm}) + \sum_u \sum_j (C_{ujm} T_{ujqm}) \\
& + \sum_w (\sum_i C_{iwm} T_{iwqm} + \sum_h C_{whm} T_{whqm}) \\
& - \sum_b (\sum_u C_{bu} T_{buq} + \sum_p C_{bp} T_{bpq}) \\
& - \sum_d (\sum_p C_{pdq} T_{pdq} + \sum_f C_{fdq} T_{fdq}) \\
& - \sum_x (\sum_p C_{pxq} T_{pxq} + \sum_f C_{fxq} T_{fxq} + \sum_h C_{xhm} T_{xhm}) \},
\end{aligned}$$

subject to:

- (2) $\sum_m (\sum_j T_{ijqm}) + \sum_b T_{ibqm} + \sum_p T_{ipqm} + G_{qq \cdot 1} \leq S_{iq} + G_{q \cdot 1q}$ for all i, q ;
- (3) $\sum_m (\sum_h T_{rhqm}) + G_{qq \cdot 1} \leq S_{rq} + G_{q \cdot 1q}$ for all r, q ;
- (4) $\sum_p T_{bpq} + \sum_u T_{buq} \leq \sum_i \sum_m T_{ibqm}$ for all b and q ;
- (5) $\sum_j \sum_m T_{ujqm} \leq \sum_b T_{buq}$ for all u and q ;

- (6) $\sum_h \sum_m T_{whmq} \leq \sum_i \sum_m T_{iwmq}$ for all w and q.
- (7) $\sum_d T_{pdq} + \sum_x T_{pxq} \leq \sum_m \sum_i T_{ipmq} + \sum_b T_{bpq}$ for all p and q;
- (8) $\sum_m (\sum_i T_{ijmq} + \sum_u T_{ujmq}) \geq D_{jq}$ for all j and q;
- (9) $\sum_m \sum_h T_{xhmq} \leq \sum_p T_{pxq} + \sum_f T_{fxq}$ for all x and q;
- (10) $\sum_p T_{pdq} + \sum_f T_{fdq} \geq D_{dq}$ for all d and q;
- (11) $\sum_d T_{fdq} + \sum_x T_{fxq} + R_{qq+1} \leq S_{fq} + R_{qq-1}$ for all f and q;
- (12) $\sum_m (\sum_w T_{whmq} + \sum_x T_{xhmq} + \sum_r T_{rhmq}) \geq D_{hq}$ for all h and q.
- (13) $T, S, D \geq 0$ for all i, j, f, q, d, b, u, p, r, h, x, and w.

The objective function (1) maximizes net social payoff or consumer plus producer surplus minus grain handling, storage, and transportation costs. Equation 2 constrains the quantity of grain shipped from each U.S. supply region to all receiving and transshipment points in each quarter to be less than or equal to the quantity supplied or carried-over by the supply region. Similarly, Equation 3 constrains quantity of grain shipped from each Mexico supply region to all receiving locations in each quarter to be less than or equal to quantity supplied or carried over. Equation 4 constrains the quantity of grain shipped from a barge-loading location in each quarter to be less than or equal to the total quantity received from all supply regions.

Equation 5 balances the inflow and outflow of grain at each barge unloading location in each quarter while equation 6 balances intercountry flows at each U.S./Mexico border crossing location. Equation 7 balances the inflow and outflow of grain at each U.S. port in each quarter. Equation 8 constrains quantity shipped by all inland transportation modes to each domestic demand region to be at least equal to or greater than the quantity demanded at each U.S. demand region in each quarter. Equation 9 constrains shipments from Mexican ports to Mexican demand regions to be less than or equal to inflows at Mexican ports. Equation 10 forces the quantity of grain received by each foreign demand region to be at least equal to or greater than the quantity demanded by each foreign demand location in each quarter. Equation 11 constrains quantity of grain shipped by each foreign excess supply region in each quarter to be less than or equal to the quantity supplied or carried over by the foreign excess supply region. Equation 12 forces quantity shipped by all inland transportation modes from Mexican ports, U.S.-Mexico border locations and Mexico supply regions to each Mexico demand region to be equal or greater than quantity demanded and equation 13 includes the non-negativity conditions.

The international corn model includes seventy-eight excess supply regions and ninety-nine excess demand regions. The excess corn supply regions include sixty-four U.S. regions, eight Mexican regions and six foreign regions (Argentina, China, France, South Africa, East Europe and Other). Included among the excess corn demand regions are sixty U.S. regions, fourteen Mexican regions and twenty-five foreign demand regions. With the exception of Japan, South Korea, China, Canada and Taiwan, the foreign excess demand regions are an aggregation of countries. The international soybean model includes eighty excess supply regions and fifty-eight excess demand regions. Sixty-eight of the excess supply regions are located in the U.S.,

eight in Mexico, and four foreign excess supply regions (Argentina, Brazil, Paraguay and Bolivia). The excess soybean demand regions include twenty-four U.S. regions, nine Mexican regions and twenty-five foreign regions.

Imbedded in the United States and Mexico portions of the models is an extensive transportation network that connects excess supply regions with excess demand regions and ports via truck, rail and barge modes. Excess supply regions are linked by truck and rail to thirty-seven barge-loading sites on the inland waterway system: the barge loading sites are linked to barge unloading sites on the inland waterway system and ports as appropriate. Seventeen U.S. ports receive corn and soybeans from the excess supply regions via truck, rail and barge as appropriate and then ship via maritime to a representative port in each of the twenty-five foreign excess demand regions. A representative port in each of the foreign excess supply regions is also linked by maritime to each of the foreign excess demand regions.

To reflect freezing of the Great Lakes and upper Mississippi waterways, the models disallow shipping via these arteries in the winter quarter. Grain handling and storage costs are incurred in United States, Mexico, and foreign excess supply regions; handling costs (loading/unloading) are incurred at U.S. excess supply locations, barge loading, and unloading locations, and ports.

Model Data

The spatial models were constructed with estimates of domestic and foreign excess demand and supply equations; grain handling and storage costs; railroad, truck, barge, and ship costs/rates. The estimated model equations and costs/rates are representative of the 1990s.

An estimated region/country excess supply elasticity in combination with its exports or estimated region surplus and region/country price facilitated the estimation of the slope and intercept parameter of an inverse excess supply function for each region/country. In a similar manner, an inverse excess demand equation was estimated for each region/country with an estimated excess demand elasticity, imports or estimated region deficit and price. The excess supply and demand elasticities for each region/country were based on the following formulations (Shei and Thompson).

$$(1) E_{es} = E_s(Q_p / Q_e) - E_d(Q_d / Q_e)$$

$$(2) E_{ed} = E_d(Q_d / Q_i) - E_s(Q_p / Q_i)$$

where,

E_{es} = excess supply elasticity of region

E_{ed} = excess demand elasticity of region

Q_d = quantity demanded or consumed in region

Q_e = quantity exported from region

Q_i = quantity imported into region

Q_p = quantity produced in region

E_d = own-price demand elasticity

E_s = own-price supply elasticity

The own-price demand elasticities (E_d) and own-price supply elasticities (E_s) to estimate region and country excess supply/demand elasticities were taken from Sullivan, Roningen, Leetmaa, and Gray. Data on production (Q_p), consumption (Q_d), exports (Q_e) and imports (Q_i) of

corn and soybeans for all foreign excess demand/supply countries came from the USDA's *Production, Supply and Distribution (PS&D)* database.

Data were not available on regional consumption (Q_d), exports (Q_e) and imports (Q_i) in the United States, thus the need to estimate these parameters for the U.S. excess supply/demand regions. Regional crop production data for the United States came from the USDA's National Agricultural Statistical Service (www2.hqnet.usda.gov/nass/). Estimates of consumption were necessary to calculate regional excess supply and demand since consumption was subtracted from production to determine whether the region was an excess supply or demand region.

In the developed corn model, the dairy, livestock and poultry sectors in the United States were responsible for 110.6 mmt (57 %) of annual corn consumption: twenty-one percent of total disappearance (45.6 mmt) was a result of exports with nearly 17 percent (37.3 mmt) due to food, industrial and alcohol processing. Remaining corn disappearance was attributed to seed use, shrink, handling loss and residual. Regional corn consumption by the dairy, livestock, and poultry sectors was calculated with information on regional populations and rations. Information on rations came from industry personnel, animal/poultry nutritionists and the USDA's *Livestock-Feed Relationships, National and State*. Regional population information came from USDA publications (U.S. Department of Agriculture, 1992-1995b, 1992-1995c, 1992-1995d, 1992-1995e). A trade publication provided information on regional corn processing capacity (dry and wet-corn milling) and in combination with national estimates of processed corn output was used to estimate regional demands (Sosland Publishing Co.; U.S. Department of Agriculture, 1989-1995).

In the U.S. portion of the international soybean model, 34.8 mmt were processed (crushed) by domestic processors, 23.2 mmt were exported and 3.5 mmt were used as seed and fed in an unprocessed form to livestock. Regional crushing demands were estimated with plant capacity estimates from the National Oilseed Processors Association and national data from USDA publications (U.S. Department of Agriculture, 1991-1994, 1995a).

The slope and intercept parameters for the inverse excess demand and supply relationships were obtained with the respective excess demand (E_{ed}) and supply (E_{es}) elasticities, imports (Q_d) and exports (Q_e) and prices. Prices in U.S. regions came from the USDA's National Agricultural Statistical Service (U.S. Department of Agriculture, 1992-1995). Information on country prices came from the USDA's *World Grain Situation and Outlook*, *World Oilseed Situation and Market Highlights* and *Oil Crops Yearbook*.

The truck, railroad, and barge transportation costs that linked U.S. excess supply and demand regions were estimated with costing codes. The barge costing code incorporated a variety of information relating to origin and destination, commodity, tons per barge, tow type, barges per tow, and fixed and variable costs. Information from the public waybill sample in combination with a railroad routing code and the rail cost code were used to estimate variable and total railroad costs for each potential routing. The estimated motor carrier costs were representative of five axle, 42 foot hopper trailers that were carrying 25 tons of grain.

Ship rates linking U.S. ports with Mexican ports and foreign excess demand regions came from an estimated regression (Fellin and Fuller). The most important grain ship routes link U.S. Gulf ports to excess demand regions in east Asia and west Europe. Estimated ship rates linking the lower Mississippi River port area to Japan, South Korea, Taiwan, and west Europe

were \$24.58, \$24.60, \$ 24.20, and \$14.87 per metric ton, respectively. Based on conversations with international grain traders, several alternative ship routes from U.S. Gulf ports to Asia destinations were identified. The most promising route involved shipping via Africa's Cape of Good Hope. Based on ship rate equations estimated by Binkley and Harrer, Fellin and Fuller and de Borger and Nonneman it was estimated that routes via the African cape to Japan, Taiwan, Korea and southeast Asia would increase relative to the Panama Canal route by \$3.12, \$2.50, \$2.70 and \$1.14 per metric ton, respectively.

Validation involved a comparison between historic export flows by U.S. port area with model-generated flows (U.S. Department of Agriculture, 1989-1995; Klindworth and Martinsen). In all cases, model-projected flows were within the ranges observed at all ports during the 1990s. Accordingly, the models were judged adequate for purposes of carrying out study objectives.

Results

Analysis is carried out to determine the effects of (1) increasing Panama Canal tolls and (2) closing the Panama Canal. Some suggest the Panamanians may attempt to elevate Canal tolls in an effort to maximize toll revenues; the first scenario evaluates the effects of this action. The second scenario evaluates the effects of closing the Panama Canal. Some believe the Panamanians will not adequately maintain the Canal, thus forcing the Canal to close for extended periods. The effects of each scenario on U.S. flow patterns, export levels and producer revenues are measured.

Effects of Increasing Canal Tolls

Ships traversing the Panama Canal are assessed tolls based on a tonnage measurement referred to as the Panama Canal Universal Measurement System (PC/UMS). The appropriate toll

rate, laden or ballast, is applied against the PC/UMS net tonnage value to determine tolls assessed each vessel. Current tolls for laden vessels are \$2.57 per PC/UMS and for ballast vessels \$2.04 per UM/UMS. Toll for laden grain vessels are estimated to currently average about \$1.50 per metric ton of cargo. In this analysis, tolls equivalent to \$2.50, \$3.50, \$4.50 and \$5.50 per metric ton for corn and soybean cargoes are evaluated.

Effects on Flow Patterns and Exports

Increasing Canal tolls reduce corn and soybean exports via U.S. Gulf ports, increase exports via Pacific northwest ports, reduce quantities traversing the Panama Canal and increase flows to Asia via the Cape of Good Hope (Africa)(Table 2). Results show a \$1 per metric ton toll increase (\$2.50/metric ton toll) reduces corn exports via Gulf ports from 31.098 mmt to 30.287 mmt, a reduction of 0.811 mmt or a 2.6 percent reduction in corn exports from the U.S. Gulf (Table 2). Corn exports via the Pacific northwest ports increase 0.624 mmt or 6.7 percent with the \$1 per ton toll increase while corn exports from other ports and total exports decline 0.096 mmt and 0.283 mmt, respectively. It is projected that the \$1 per ton increase in toll would lower U.S. corn flow via the Canal by 1.213 mmt or 7.4 percent (Table 2). In general, the \$1 per ton increase in toll did not yield important changes in corn or soybean flows.

The most dramatic affect on corn and soybean flows (% change in flow) occur at Pacific northwest ports, the Panama Canal and Africa's Cape of Good Hope when Canal tolls are increased \$2 per ton or more. Corn exports via the Pacific northwest are projected to increase about 25 percent with a \$2 per ton toll increase and about 38 percent with an increase of \$3 or \$4 per ton. Soybean exports to the Pacific northwest increase about 4 percent with a \$1 per ton toll increase, about 24 percent with a \$2 per ton toll increase, and over 100 percent with a toll

increase of \$3 per ton. Projected corn and soybean flows to the Pacific northwest ports reach a maximum of about 12.926 mmt and 3.398 mmt, respectively, with toll increases of \$3 or \$4 per ton. Projected corn flows via the Pacific northwest do not exceed the historical maximum (15.604 mmt), however, soybean flows do exceed the historical maximum of 2.096 mmt established in 1995. The projected increase in corn and soybean exports at Pacific northwest ports are rail-carried from origins in Minnesota, Iowa, Nebraska and North and South Dakota. As flows to the Pacific northwest increase, there are corresponding declines in the quantity of corn and soybeans entering the upper Mississippi River.

The analysis show U.S. corn and soybean exports to Asia commence routing via the African cape when Canal tolls increase about \$2 per ton (equivalent to \$3.50/ton toll). In particular, with a toll increase of \$2 per ton, a projected 0.037 mmt of corn and 1.712 mmt of soybean pass the African cape for destinations in east Asia, whereas with a \$3 per ton toll increase, an estimated 3.4 mmt of corn and 5.47 mmt of soybeans are routed via the cape. An estimated 12.852 mmt of U.S. corn and soybeans pass via the cape when tolls increase \$4 per ton (Table 2).

Although flows are altered with higher Canal tolls, total U.S. exports are modestly impacted. The most dramatic affect is on corn when tolls increase \$4 per ton and U.S. exports decline 2 percent or about 0.92 mmt (Table 2). As U.S. corn exports decline, the exports of France, China and other exporters increase to offset the U.S. decline. Increases in the Panama Canal toll have a comparably small affect on U.S. soybean exports.

Increasing Panama Canal tolls reduce the role of the U.S. in the Asian corn market while increasing U.S. exports to Europe and north Africa. In particular, a \$4 per ton increase in

the Canal toll is projected to increase U.S. exports to Europe and Africa about 3.60 mmt while exports to Asia decline similarly. Argentina, France and China replace the U.S. in the Asian corn market as Canal tolls increase. Similarly, as Canal tolls on soybean-laden vessels increase, the role of the U.S. in Asian markets decline, however, in Europe the role of the U.S. increases. Brazil and Argentina are projected to increase their role in Asia as Canal tolls increase.

Results show a relatively inelastic relationship between toll rate increases and quantity traversing the Canal when tolls increase \$1 and \$2 per ton. For example, a revenue-maximizing Canal operator could increase revenues by adjusting tolls upward by \$2 per ton (equivalent to \$3.50/ton toll on cargo) on corn-laden vessels and by adjusting tolls upward by \$1 per ton (equivalent to \$2.50/ton toll) on soybean-laden vessels. Toll rate increases above these levels would unfavorably affect revenues of the Canal operator. Regardless, a revenue-maximizing Canal manager would substantially increase tolls on corn and soybean-laden vessels. The following section attempts to measure the effect of increasing Canal tolls on revenues of U.S. corn and soybean producers.

Effects on U.S. Producer Revenues

As Canal tolls increase, the transportation costs linking the U.S. to importers in east Asia and the west coasts of South and Central America also increase. This tends to lower prices in U.S. regions that ship via the Canal while increasing prices in the importing regions. A \$1 and \$2 per ton increase in the Canal toll increases corn prices in Japan, Taiwan and South Korea from \$0.72 to \$1.28 per ton, while U.S. regions that ship via the Canal experience price reductions ranging from \$0.09 to \$0.25 per ton when the Canal toll increases by \$1 per ton and declines in price that range from \$0.42 to \$0.64 per ton when the toll increases \$2.00 per ton. For soybeans,

a \$1 and \$2 per ton toll increase would increase Japan, Taiwan, and South Korea prices from \$0.53 to \$1.18 per ton, whereas prices in U.S. regions that ship via the Canal decrease \$0.09 to \$0.43 per ton with a \$1 per ton increase in toll and decrease \$0.20 to \$0.54 per ton with a \$2 toll increase.

Most U.S. corn and soybean production regions experience a decline in price when tolls increase, however, prices increase in selected U.S. regions. In particular, prices in U.S. regions that export to Asia via Pacific northwest ports modestly increase as tolls increase. This is the result of the higher prices in the Asian destination markets and the ability of these U.S. regions to access the Asian market without traversing the Panama Canal. Regions whose prices are favorably impacted include Nebraska, west Iowa, southwest Minnesota, and east North and South Dakota.

As expected, revenues of most U.S. corn and soybean producing regions decline as toll rates increase (Table 3). A \$1 per ton toll increase is projected to annually reduce corn and soybean producer revenues about \$60 and \$36 million, respectively, while a \$2 per ton increase reduces respective annual revenues about \$125 and \$51 million (Table 3). The largest declines in producer revenues are in Illinois.

Effects of Canal Closure

Effects on Flow Patterns and Exports

Closing the Panama Canal has important effects on U.S. corn and soybean exports via U.S. Gulf ports, the Pacific northwest and the routing of exports to Asia via the Cape of Good Hope (Africa). Corn and soybean exports via Gulf ports decline a respective 5.50 mmt (18 % decline) and 2.29 mmt (13 % decline) with Canal closure while respective exports via the Pacific

northwest ports increase 4.61 mmt (49 % increase) and 2.13 mmt (126 % increase) (Table 2). Projected corn exports to Pacific northwest ports (14 mmt) are less than the historical maximum (15.6 mmt) while soybean exports (3.8 mmt) exceed the historical maximum (2.09 mmt) by 82 percent. A projected 12.50 mmt of U.S. corn and soybean exports are routed to Asia via the African cape with closing of the Canal.

Results suggest Canal closing does not have a devastating affect on U.S. export levels. Corn exports decline about 2 percent (0.90 mmt) with Canal closing while soybean exports decline nearly 1 percent (0.20 mmt). Corn and soybean exports of competing exporters are projected to increase with Canal closure so total international trade is almost unchanged. Although aggregate trade levels are nearly unchanged, the share of various import markets supplied by the major exporters is altered. The U.S.'s share of Asian corn and soybean import markets decline, while U.S. exports to some import regions increase. Most affected is Europe which increases corn and soybean imports from the U.S. while decreasing imports from Argentina and Brazil. In contrast, the Asian import markets increase corn and soybean imports from Argentina, Brazil and France while decreasing imports from the United States.

Effects on U.S. Producer Revenues

In general, closing the Panama Canal has similar affects on prices and revenues as does increasing Canal tolls. Production regions in the United States whose exports have historically traversed the Panama Canal experience a decline in price with Canal closing while those regions which ship to the Pacific northwest ports enjoy an increase in price. This occurs because the transportation costs required to access the important Asian markets increase with Canal closing, thus reducing prices in U.S. production regions that have historically exported via the Canal and

increasing prices in Asian markets. This yields an increase in Pacific northwest port prices and prices in those U.S. regions which ship via this outlet.

Closing the Panama Canal would annually reduce U.S. corn and soybean producer revenues about \$207 and \$96 million, respectively. The largest revenue losses are in Illinois with estimated annual declines in corn and soybean revenues of \$76 million or about 25 percent of total revenue losses (\$303 million) (Table 3).

Summary and Conclusions

Spatial models of the international corn and soybean sectors are used to evaluate the effect of increasing Panama Canal tolls and closure of the Canal. Increasing tolls reduce corn and soybean exports via U.S. Gulf ports, increase exports via U.S. Pacific northwest ports, reduce quantities transiting the Canal and increase flows to Asia via Africa's Cape of Good Hope. Increasing the Canal toll from the current \$1.50 to \$2.50 per ton of cargo would have a modest affect on corn and soybean flows and exports. However, when tolls are increased \$2 per ton or higher (equivalent to a \$3.50 per ton toll and higher) important shifts in flows occur. Corn exports to Pacific northwest ports increase from 25 to 40 percent while soybean exports increase from 24 to over 100 percent when tolls are increased \$2, \$3 and \$4. Similarly, when tolls are increased \$2 per ton or higher, flows commence via the African cape. With a \$2 per ton toll increase, about 1.8 mmt are routed via the cape and with \$3 and \$4 per ton toll increases the quantities increase to 8.9 and 12.9 mmt, respectively. Further, the analysis shows flows between international trading partners would be altered. The U.S.'s role in Asia's corn and soybean markets decline while Europe and north Africa become increasingly important markets for U.S. exports. Argentina, Brazil, China and France become more important suppliers to Asia at

increased toll levels. The U.S.'s share of the international market declines by no more than 2 percent with higher tolls. Finally, the analysis suggests a revenue-maximizing Canal operator could substantially increase revenues by adjusting tolls upward by \$2 per ton (equivalent to \$3.50/ton toll) on corn-laden vessels and \$1 per ton (equivalent to \$2.50/ton toll) on soybean-laden vessels. Toll rates above these levels would reduce Canal revenues. A \$1 per ton toll increase is projected to annually reduce U.S. corn and soybean producer revenues about \$60 and \$36 million, respectively, while a \$2 per ton increase reduces respective revenues about \$125 and \$51 million. If the Canal operator were to increase tolls \$4 per ton, U.S. producers' corn and soybean revenues are projected to decline \$248 million per year.

Closing the Canal would affect flows in a similar manner as increased tolls. Corn and soybean exports via the U.S. Gulf decline 7.8 mmt, while exports via Pacific northwest ports increase 6.7 mmt and routings via the African cape increase to 12.5 mmt. Finally, Canal closure is projected to annually reduce revenues of U.S. corn and soybean producers \$303 million.

In summary, the Panama Canal is an important transport artery for U.S. grain and soybean exports. Its annual value to U.S. corn and soybean producers is in excess of \$300 million, i.e., closing the Canal would annually lower producer revenues by this amount. Further, analysis shows that a revenue-maximizing Panama Canal operator would substantially increase tolls above current levels on corn- and soybean-laden vessels.

Table 1. Subscripts, Parameters and Variables Included in Formulated Models

Subscripts:	
q	quarter (1, 2, 3, 4)
i	U.S. excess supply regions ($i = 1, 2, 3, \dots, m$)
r	Mexico excess supply regions ^o = 1, 2, 3, ..., m)
f	Foreign exporting regions ($f = 1, 2, 3, 4, m$)
j	U.S. excess demand locations ($j = 1, 2, 3, \dots, m$)
h	Mexico excess demand regions ($h = 1, 2, 3, \dots, m$)
d	Foreign importing regions ($d = 1, 2, 3, \dots, m$)
m	Inland modes of transportation ($m = 1, 2, 3$)
b	Barge loading locations ($b = 1, 2, 3, \dots, 37$)
u	Barge unloading locations ($u = 1, 2, 3, \dots, 5$)
p	U.S. ports ($p = 1, 2, 3, \dots, 17$)
w	U.S.-Mexico border crossing locations ($w = 1, 2, 3, \dots, 5$)
x	Mexico ports ($x = 1, 2, 3, \dots, 5$)
Parameters:	
C	Transportation and grain handling cost per metric ton for truck, railroad, barge and ship modes as appropriate
K	storage cost per metric ton
Variables:	
S_i	U.S. excess supply regions
S_r	Mexico excess supply regions
S_f	Foreign excess supply regions
D_j	U.S. excess demand regions
D_h	Mexico excess demand regions
D_d	Foreign excess demand regions
T	Grain flow in metric tons between nodes
G	Quantities of grain stored in the United States and Mexico per quarter
Z	Quantities of grain stored in other major exporting countries per quarter

Table 2. Estimated Changes in U.S. Corn/Soybean Flows Resulting from Increasing Panama Canal Tolls and Closing of the Panama Canal (millions of metric tons (mmt))

Routing	Base Quantities	\$1/ton toll increase	% change	\$2/ton toll increase	% change	\$3/ton toll increase	% change	\$4/ton toll increase	% change	Canal close	% change
	---mmt---	-----Change in Corn Flows (mmt)-----									
U.S. Exports via Gulf	31.098	-0.811	-2.6	-2.562	-8.2	-4.088	-13.2	-4.133	-13.3	-5.504	-17.7
U.S. Export via PNW	9.351	0.624	6.7	2.395	25.6	3.595	38.4	3.543	37.9	4.615	49.4
Other U.S. Exports	5.211	-0.096	-1.8	-0.259	-4.9	-0.334	-6.4	-0.332	-6.4	-0.014	-0.2
Total U.S. Exports	45.660	-0.283	-0.6	-0.426	-0.9	-0.827	-1.8	-0.922	-2.0	-0.901	-2.0
U.S. Exports via Panama Canal	16.318	-1.213	-7.4	-4.952	-30.3	-11.767	-72.1	-14.007	-85.8	0	100.0
U.S. Exports via Cape of Good Hope (Africa)	0	0	0	0.037	∞	3.4	∞	5.567	∞	4.959	∞
	---mmt---	-----Change in Soybean Flows (mmt)-----									
U.S. Exports via Gulf	18.108	-0.125	-0.7	-0.493	-3.0	-1.797	-9.9	-1.360	-7.5	-2.294	-12.6
U.S. Export via PNW	1.684	0.060	3.6	0.406	24.1	1.714	101.7	1.285	76.4	2.128	126.4
Other U.S. Exports	3.351	-0.011	-0.3	-0.019	-0.6	-0.020	-0.6	-0.022	-0.7	-0.036	-1.1
Total U.S. Exports	23.143	-0.076	-0.3	-0.106	-0.4	-0.103	-0.4	-0.097	-0.4	-0.202	-0.90
U.S. Exports via Panama Canal	9.992	-0.922	-9.2	-4.363	-43.7	-7.226	-72.3	-8.612	-86.2	-9.992	-100.0
U.S. Exports via Cape of Good Hope (Africa)	0	0	0	1.712	∞	5.470	∞	7.285	∞	7.558	∞

Table 3. Estimated Annual Reduction in U.S. Corn/Soybean Producer Revenues Resulting from Increasing Panama Canal Tolls and Closing of the Panama Canal (\$ millions)

Region	\$1/ton toll increase	\$2/ton toll increase	\$3/ton toll increase	\$4/ton toll increase	Canal close
-----Decrease in corn producer revenues (\$ millions)-----					
Iowa	10.5	13.7	20.2	20.7	22.1
Illinois	14.7	34.2	53.2	54.5	58.3
Indiana	8.3	20.2	30.0	30.7	32.9
Michigan	2.1	5.2	7.7	7.9	8.4
Minnesota	6.3	15.8	23.3	23.8	25.4
Ohio	4.1	11.3	16.9	17.4	18.6
Other States	13.5	24.1	37.6	38.7	41.5
Total	59.5	124.5	188.9	193.7	207.2
-----Decrease in soybean producer revenues(\$ millions)-----					
Arkansas	2.7	3.9	4.3	4.8	8.3
Iowa	4.0	6.1	5.9	5.9	11.4
Illinois	8.4	11.1	10.4	9.3	17.7
Indiana	3.9	5.1	5.5	4.9	9.4
Minnesota	3.6	4.5	4.3	4.4	6.5
Ohio	2.2	3.6	4.0	4.5	8.1
Other States	11.3	17.1	18.6	20.1	35.0
Total	36.1	51.4	53.0	53.9	96.4

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