THE IMPACTS OF THE PANAMA CANAL EXPANSION ON WORLD COTTON TRADE

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Abstract:

The U.S. cotton industry is highly dependent on foreign markets. It is important for the U.S. industry to remain competitive with foreign suppliers such as Brazil, India and Uzbekistan. One of the major factors that will affect the efficiency, distribution and competitiveness of U.S. cotton will be the expansion of the Panama Canal. With sea freight the fastest growing mode of transportation, the number and size of vessels that are able to pass through the Canal will increase after the expansion is completed in 2014. In summary, taking into account the cost structure, transit time, and the Panama Canal tolls, when compared to the intermodal option, the expansion is expected to reduce maritime costs for shipments from the East Coast ports (e.g. Savannah port) to East Asia (China) by about $140/TEU, a 28 percent reduction of the current total cost of $490/TEU. A spatial, intertemporal equilibrium model of the international cotton sector was utilized to evaluate the effects of the expansion on the world cotton industry, with more emphasis given to the U.S. cotton industry. By assuming that the canal expansion will be completed in 2014, three scenarios assuming different reductions in ocean freight rates from the U.S. Gulf and Atlantic ports to Asian and Pacific importing countries are analyzed. In general, all scenarios suggested that cotton exports to Gulf and Atlantic ports would increase considerably with the port of Savannah leading the way. On the other hand, the Long Beach – Los Angeles ports would decrease its participation in total U.S. cotton exports significantly. Overall, the percentage of U.S. cotton exports via the Panama Canal relative to the total U.S. cotton exports would increase. Furthermore, total U.S. cotton exports were expected to increase due to the expansion. However, in relative terms, the maximum amount which the U.S. total exports would increase is equivalent to a 2.2 percent increase. As for the other competing countries, for all analyzed scenarios, these losses in exports, prices, and revenues are very modest in relative terms.

INTRODUCTION

U.S. Cotton Industry and Trade Overview

In the last two decades, the U.S. cotton sector has faced a number of challenges as domestic mill demand has declined and U.S. exports have increased. During the 1990s, for example, domestic mill demand accounted for about fifty percent of available cotton supplies. Due to the decrease in domestic textile production caused by cheap backhauls and competition from imported textile and apparel products, U.S. mill use dropped to 30 percent of cotton supply for 2000-2005 and has averaged less than 20 percent annually since then (FAS/USDA 2011). The resulting surplus forced the industry to look for alternative markets. Significant changes in the global market for cotton and cotton-based products, particularly an increase in export demand, have provided overseas markets for U.S. cotton. As a result, U.S. cotton exports rose to 17.7 million bales in 2005/06, more than triple the levels of a decade earlier, before settling at about 13 million bales in recent years. This large and rapid increase in exports made the U.S. the largest supplier of cotton to the world market, with an export forecast that will account for 41 percent of world trade in 2010/2011 (FAS/USDA 2011).

The major final destination for U.S. cotton is China. China has emerged as the world's largest cotton importer, creating a strong, but somewhat volatile market for U.S. cotton. In 2010, about 31 percent of all world cotton exports went to China (FAS/USDA 2011). The United States is responsible for about 40 percent of China's total cotton imports, representing 26 percent of U.S. cotton production. China has been the leading market for U.S. cotton since 2003 and imported 4.9 million bales in 2010, down significantly from 7.6 million bales in 2006, but up from 2.8 million bales in 2009. Turkey is currently the second leading export market for U.S. cotton, importing 2.1 million bales during 2010, down from a peak of 2.7 million bales in 2007, but up from 1.6 million bales in 2008 and 1.8 million bales in 2009 (WISERTrade 2010).

Panama Canal Expansion (PCE) and the U.S. Cotton Industry

The U.S. cotton industry is highly dependent on foreign markets. It is important for the U.S. industry to remain competitive with foreign suppliers such as Brazil, India and Uzbekistan. One of the major factors that will affect the efficiency, distribution and competitiveness of U.S. cotton will be the expansion of the Panama Canal. With sea freight the fastest growing mode of transportation, the number and size of vessels that are able to pass through the Canal will increase after the expansion is completed in 2014. The new Panama Canal locks system will be equipped to handle post-Panamax vessels, up to 12,600 twenty-foot equivalent units (TEU) for containers, compared to a present maximum vessel size of 4,400 TEU (Panamax).

This expansion is necessary not only to accommodate growing commerce, but also because post-Panamax vessels are forecast to account for nearly 25 percent of cargo vessel capacity by 2012 and already account for 35 percent of all vessels carrying cargo worldwide (ACP 2007). The PCE will likely have a role in relieving U.S. West Coast congestion on routes to Asia and potentially increase cotton shipments from the U.S. Gulf and South Atlantic ports to China and other Asian destinations. Drewry Supply Chain Consultants, a maritime industry research firm, projects that the West Coast ports will see increased competition from the post-expansion Panama Canal and noted that the East Coast and Gulf Coast ports could seize up to 25 percent of the traffic coming into the West Coast (CanagaRetna 2010). In addition, U.S. ports have experienced a 156% increase in post-Panamax vessel calls over the past five years, increasing the demand for service of larger vessels (USDOT 2009).

Panama Canal expansion has the potential to increase U.S. cotton exports as the expansion takes place. In 2010, approximately 1.34 million bales of the total U.S. cotton exports originated in the ports of Norfolk, Charleston, and Savannah with final destination East Asia (WISERTrade 2010). Since historically only 6 percent of the total U.S. exports to East Asian countries transited the Suez Canal (Salin 2010), one can conclude that most of these 1.34 million bales cotton exports from the top three Atlantic ports (Norfolk, Charleston, and Savannah) to East Asian countries were via the Panama Canal. This accounts to nearly 10 percent of the total U.S. cotton exports, which were 14 million bales for the 2010 calendar year (WISERTrade 2010).

In addition, due to the present lack of capacity at the Panama Canal to handle post-Panamax vessels, U.S. cotton exports were shipped via Panamax vessels. Therefore, while yet to be verified empirically, as the canal is expanded and post-Panamax vessels are capable of transiting the canal, significant additional volume of U.S. cotton is expected to be shipped via Gulf Coast and East Coast ports to China and the Far East after 2014.[1]

However, it is important to consider the potential of the Panama Canal route after the expansion. First, the effects of PCE on cost structure of operating containership vessels are evaluated. According to Rodrigue (2010) a standard Panamax (4,000 TEUs) container ship has annual operating costs of about $2,314/TEU. Meanwhile, post-Panamax (10,000 TEUs) vessels have the potential to reduce annual operating costs by up to $1,450/TEU. So, in terms of cost structure, the expansion of the Panama Canal will enable maritime shippers to reduce all-water costs by approximately $860/TEU, or 37 percent. Therefore, the economies of scale, which larger ships offer to maritime companies, will be one economic benefit of the PCE.

Another important factor for maritime shippers is the transit time between origin and final destination. When the all-water route via the Panama Canal is compared to the intermodal option (rail to West Coast ports) to a common final destination[2], the former has an average transit time of between 21.6 and 25 days, which is approximately 5 to 7 days longer than the latter (Salin 2010; Rodrigue 2010). Estimates indicate that the all-water route maritime cost is about $490/TEU less than the intermodal option (Ashar 2009). This indicates that the cost differential in term of dollars per TEU corresponds to cost savings of $70-$75/TEU/day[3]. As the Panama Canal is expanded, this cost savings is expected to increase to the range of $100-$125/TEU/day (Ashar 2009), which is equal to a cost of differential of at least $700/TEU. This implies that the PCE is expected to reduce maritime cost by at least $210/TEU for the East Coast ports via the Canal to East Asia ($700/TEU - $490/TEU = $210/TEU).

This possible outcome must be cautiously analyzed since the tolls charged by the Panama Canal Authority could reduce part of the significant gains of the expansion. There are reports that the canal administration has substantially increased tolls from $40/TEU in 2006 to $72/TEU in 2009, which represents a rise of 80 percent (Ashar 2009). This indicates that the toll increase has already offset nearly one-third of the potential gains of the expansion ($72/TEU of $210/TEU).

[1] This in large part, however, will depend on the expansion of the East coast ports to handle post-Panamax vessels. While East Coast ports such as Savannah, Charleston and Norfolk are in position to benefit initially from the expansion of post-Panamax vessel trade, the amount of additional cargo that may be handled is uncertain until improvements are made in capacity and water depth (CanagaRetna, 2010).

[2] Considering the same origin (East Coast, e.g. Savannah port) and destination (East Asia, e.g. Shanghai port, China).

[3] By dividing the values between the range of $490-$500/TEU by the range of 5 – 7 days, one can get the $70-$75/TEU/day.

The after toll potential savings is equal to nearly $140/TEU which gives a new cost differential of $90/TEU/day ($630/TEU/7 days) instead of the pre-toll premium of $100/TEU/day ($700/TEU/7 days). In summary, taking into account the cost structure, transit time, and the Panama Canal tolls, when compared to the intermodal option, the PCE is expected to reduce maritime costs for shipments from the East Coast ports (e.g. Savannah port) to East Asia (China) by about $140/TEU. This reduction in maritime costs represents 28 percent of the current total cost of $490/TEU. Overall, the PCE is expected to be a cost-effective export route for U.S. cotton.

STUDY OBJECTIVES AND PROCEDURES

Main Objectives

The main objectives of this study are: (i) to assess the impact of the PCE on the U.S. cotton industry by examining U.S. cotton export flows by final destination, changes in export levels, and warehouse revenues and (ii) to evaluate the effects of PCE on the global cotton distribution and competitiveness by focusing on competing country exports and producer revenues.

Procedures

To accomplish the main objectives, three scenarios are examined. The first scenario evaluates the effects of a small reduction (10 percent) in ocean freight rates for vessels originating from the U.S. Gulf and South Atlantic ports to Asian and Pacific countries due to the PCE. The second scenario assumes a larger reduction (28 percent) in ocean freight rates for the same origins and destinations. Such reduction takes into account the total savings generated by the PCE, when compared to the intermodal option[4]. Last, due to a responsive measure to offset decrease in competitiveness with respect to the Gulf and South Atlantic ports, the third scenario goes one step ahead and introduces a 10 percent reduction in ocean freight rates from West Coast ports (Los Angeles-Long Beach) to Asian and Pacific countries along with the 28 percent reduction of scenario two. In other words, scenario three emulates a situation where the West Coast and Gulf and East ports would compete between themselves to attract more vessels and, hence, enhance their capabilities to export more cotton.

METHODOLOGY

Spatial Price Equilibrium Model

The cotton model used to accomplish research objectives is a spatial, intertemporal equilibrium model of the international cotton industry. This model is a quadratic programming model that generates interregional trade flows and prices. The objective function specifies the maximization of producer and consumer surplus minus cotton handling, storage, and transportation costs (Samuelson 1952; Takayama and Judge 1971). The model includes considerable detail on regional excess supplies and demands as well as transportation, storage,

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[4] The PCE is expected to reduce maritime costs for shipments from the East Coast ports to East Asia by about $140/TEU. This reduction in maritime costs represents 28 percent of the current total cost of $490/TEU.

and cotton handling costs in both the U.S and Brazil. Other cotton trading countries are considered as either an excess supply or an excess demand region.

The international cotton model employed in this analysis includes 567 excess supply regions and 46 excess demand regions. The excess cotton supply regions include 410 U.S. regions (warehouses), 152 Brazilian regions (farm level) and 5 foreign regions (Australia, India, Sub-Sahara Africa, Uzbekistan, and all other exporting countries). Included among the excess cotton demand regions are 11 U.S. regions (domestic mills), 21 Brazilian regions (domestic mills), and 15 foreign demand regions (Bangladesh, China, EU-27, Hong Kong, Indonesia, Japan, Mexico, Pakistan, Rest of South America, South Korea, Taiwan, Thailand, Turkey, Vietnam, and all other importing countries).

The U.S component of the model is a detailed transportation network that links excess supply regions with excess demand regions and ports via truck (truck chassis and flatbed) and rail. Excess supply regions are connected to excess demand regions within the U.S. via truck. There are 15 U.S. ports which are linked to the excess supply regions either by truck direct shipments or truck to 5 intermodal (rail loading) sites. These 15 U.S. ports are then linked to the excess demand regions via vessels. The exception is Mexico where land border port crossings are used exclusively. A representative port in each of the foreign excess supply regions is also linked by ocean freight costs to each of the foreign excess demand regions.

Similarly, the Brazilian component was established by 152 excess supply sub-regions/states and 21 excess demand regions (mills) in Brazil. The 152 cotton excess supply sub-regions/state in Brazil were at the municipality level for the states of Mato Grosso, Bahia, and Goiás. The remaining excess supply regions in Brazil were considered at the state level. The excess demand regions in Brazil were represented at the state level by determining their physical location within the primary cotton consuming states. Excess supply regions are connected to excess demand regions within Brazil solely by truck. Five ports are linked to the excess supply regions by direct truck shipments. These five Brazilian ports are then linked to the excess demand regions via vessels.

Routinely, a major portion of excess supply is exported or consumed domestically during the harvest period. The rest of the production is stored for alternative shipment to port terminals or other domestic demand locations. The quantities consumed and supplied per quarter are endogenously determined by the model. No cotton stocks were considered in the model. The assumptions for the model were that cotton is a homogenous commodity, nondiscriminatory trade policies exist, and system of balanced equations prevailed. The objective of the model was to maximize the summation of producer surplus and consumer surplus subtracting transportation and handling costs. See Appendix for mathematical representation of model.

Model Data

The spatial model was constructed with estimates of cotton production and consumption in excess supply and excess demand regions for the U.S. and Brazil as well as other major exporting and importing countries. Estimated excess supply and demand locations for the U.S. were based on the optimal solution generated by a cost minimizing mathematical programming model developed by Fraire et al. (2011) to represent the U.S. cotton transportation and logistical system as well as excess supply and demand locations for 2008. The model framework developed by Fraire et al. (2011) minimizes the total cost of shipping, handling, and storing cotton that originates at 811 gins and flows to 415 warehouses across the U.S. over four quarterly periods. The model allows routing cotton shipments from originating gins to warehouses and then to sixteen U.S. ports, eleven domestic mill regions, or four major intermodal facilities and then by rail to major West Coast, Gulf and East Coast ports.

The optimum solution to the least cost model is used to represent the excess supply and demand locations in the intertemporal, spatial price equilibrium model within the U.S. cotton industry. The excess supply locations are representative warehouses which were considered to receive cotton shipments from the gins. Similarly, the excess demand locations are domestic mills which use domestic cotton originating from the warehouses. The solution to the least cost model indicated that there are 410 optimal warehouses and 11 domestic mills within the United States. The location of the warehouses is distributed in several states with Texas having the most warehouses (90) followed by Georgia (62) and North Carolina (44). As for the domestic mills, there are 11 optimal locations which are located in the following states: Alabama (2), Georgia (2), North Carolina (2), South Carolina (2), Tennessee (1), Texas (1), and Virginia (1).

By using the optimal solution of the least cost model to indicate the location of the warehouses and their cotton supply, it is estimated the share of each warehouse with respect to the total supply. Each warehouse share with respect to the total warehouse supply was then utilized to estimate the ending stock and surplus for each excess supply region based on data from FAS/USDA (2011). Domestic mill locations and their cotton demand were used to calculate the consumption share by mill. Then, by multiplying the total consumption, with source from FAS/USDA (2011) to the calculated consumption share, mill demand of each excess demand region was quantified. Surplus/deficits were calculated by subtracting the total consumption and ending stock from the total supply. If the final value is positive, the region has a surplus and thus an excess supply. On the contrary, if the final value is negative, the region has a deficit and thus has an excess demand.

In order to estimate production and consumption of cotton in excess supply (demand) regions in Brazil, several efforts were made based on data from IBGE/MPOG (2011), RAIS/MTE (2011), and FAS/USDA (2011). First, the cotton production share of different regions/states in Brazil was estimated for 2008 and 2009 with data from IBGE/MPOG (2011)[5]. The share was then used to estimate the supply and total domestic consumption. Supply was composed by production, beginning stock, and imports. Since there is no data for beginning stock and imports on city-level, these values were obtained by multiplying the share by the total beginning stocks and total imports for Brazil, which was sourced from the FAS/USDA (2011) for 2008/09. The production by region was also a multiplication of production share (IBGE/MPOG 2011) and the total production (FAS/USDA 2011) for 2008/09. The same procedure was applied to calculate the ending stocks. The region/state domestic consumption was estimated in the following way. The number of active mills by each region/state was retrieved from RAIS/MTE (2011) and was assumed to represent the consumption of these regions/states. Then, by multiplying the total consumption, by the calculated consumption share, mill demand of each region was quantified. For the exporting and importing countries, the data for exports and imports were sourced from FAS/USDA (2011).

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 demand equation was estimated for each region/country with estimated

[5] The IBGE/MPOG (2011) provides cottonseed production by municipality level and not cotton plume data. Therefore, it was assumed that the cotton plume production share was the same as the cottonseed production share.

excess demand elasticity, imports, or estimated region deficit and price. The following equation was used to estimate excess supply elasticity for each exporting region (Shei and Thompson 1977):

$$(1)\ E_{ES}=E_S(Q_P/Q_E)-E_D(Q_D/Q_E)$$

where, E_{ES} is the excess supply elasticity of a region, E_S is the own-price supply elasticity of a region, Q_P is the quantity produced in a region, Q_E is the quantity exported from a region, E_D is the own-price demand elasticity of a region, and Q_D is the quantity demanded or consumed in a region.

In the case of the excess supply regions for the U.S. cotton industry, each region was exporting all of its surplus (warehouses), which indicates that the sum of the quantity demanded (Q_D) for the warehouses was equal to zero. Hence, the excess supply elasticity for the warehouses was equal to its own-price supply elasticity ($E_{ES} = E_S$). Similarly, the Brazilian excess supply regions had zero demand, thus the excess supply elasticity is equivalent to its own-price elasticity. Supply elasticities by U.S. cotton producing regions were taken from Pan et al. (2006). The cotton price supply elasticities were 0.18 and 0.16 for the warehouses located in the Delta (Arkansas, Missouri, Tennessee, Louisiana, and Mississippi) and Southeast (Alabama, Georgia, Florida, North Carolina, South Carolina, and Virginia) regions, respectively. As for the Southwest (Texas, Kansas, Oklahoma, and New Mexico) and West (California and Arizona) producing regions, the supply elasticities were assumed to be 0.34 and 0.42, respectively. As for the Brazilian regions, for simplicity, the supply elasticity was equal to 0.62 and was assumed to be equal across the country (Shepherd 2006).

Similar to the excess supply elasticity equation, the excess demand elasticity equation is represented as (Shei and Thompson 1977):

$$(2)\ E_{ED}=E_D(Q_D/Q_I)-E_S(Q_P/Q_I)$$

where, E_{ED} is the excess demand elasticity of a region, E_S is the own-price supply elasticity of a region, Q_P is the quantity produced in a region, Q_I is the quantity imported into a region, E_D is the own-price demand elasticity of a region, and Q_D is the quantity demanded or consumed in a region. As in the case of the excess supply regions, for both the U.S. and Brazilian excess demand regions (mills), each mill had quantity produced (Q_P) equal to zero. Thus, the excess demand elasticity was equal to its own-price demand elasticity ($E_{ED} = E_D$). Domestic own-price elasticity for the U.S. mills was equal to -0.24 and was also taken from Pan et al. (2006). As for the Brazilian mills, the source for the own-price elasticity is Poonyth et al. (2004) and is equal to -0.60.

With respect to the transportation network, cotton handling, and storage charges data of the U.S. portion of model, this study used the estimations from Fraire et al. (2011). In their work, road mileages for trucking between originating gins, warehouses, intermodal facilities, ports, and mill locations were calculated using standard mapping software. Railroad mileages between intermodal or boxcar origins and port destinations were obtained from relevant railroad industry websites. Trucking cost base rates and fuel surcharges were developed based on information collected from various industry sources. These data were used to estimate statistical relationships between trucking mileage and cost. The resulting regression parameters were used to derive point estimates of trucking costs for the specific distance matrix elements for all ginwarehouse, warehouse-intermodal, warehouse-port, and warehouse-mill combinations. Shipping costs from intermodal points to ports were calculated using rail mileage multiplied by the average representative railroad rates obtained from the Surface Transportation Board, railroad industry representatives, and cotton shippers.

In the Brazilian cotton industry, virtually all cotton shipment from supply (farm) to either demand (mills) or exporting ports occur by truck. Independently of the distance of the cotton haul, truck is the transportation mode used in Brazil. The truck costs in this study were calculated based on the monthly data from CEPEA (2011) for the years 2007 to 2009. The truck cost data is originally in Brazilian currency (R$) per kilometer. Hence, the monthly nominal exchange rate of the R$ to the U.S. dollar was calculated using data available from ERS/USDA (2011). Table A6 below presents a summary statistics of the truck cost and distance of Brazilian cotton interregional shipments. As we can see, the average distance of cotton hauling in Brazil is 866 miles, with minimum and maximum of 44.73 and 2,056 miles, respectively. Average truck cost is $20.32 per bale with standard deviation of 6.89.

Truck costs were estimated with a linear equation based on the distance between shipping points and receiving locations. The following equation was estimated and served as a tool to measure truck transportation costs:

(3) US$/bale = 7.38 + 0.0149*miles + 1.09*DQ3

where the intercept represented the fixed cost (loading and unloading costs) in dollars per bale and the slope accounted for the variable cost per bale/mile (transportation costs). DQ3 is a dummy variable that represent seasonality. The sign for the dummy variable was as expected. The harvest quarter for cotton in Brazil is for the months of July, August, and September (CONAB/MAPA 2011a). The coefficient was positive which means a higher truck cost is charged to transport cotton for that quarter of the year. The R-square for this equation was 0.565. The intercept and the coefficient for the miles were significant at the 0.01 level. The dummy variable DQ3 was significant at the 0.01 level.

The port charges for the Brazilian exporting ports were based on estimations from Mello (2010) and Lomanto (2011). According to Mello (2010), the current port charges for the ports of Santos and Paranaguá are approximately $11.11/bale and $9.77/bale, respectively. As for the port of Salvador, the current port charges estimate is $8.97/bale. It is important to note that these estimates are accounting for all of the cotton handling and taxes by port. In other words, the port charges for these studies represent truck unloading, container stuffing, tracking certificate, container handling, and other related port obligations. Regarding the port capacity, no ports were forced to have the amount exported to meet a certain capacity.

The estimates of ocean freight rates from U.S. ports as well as Brazilian ports to different foreign excess demand regions were estimated based on the difference between the cotton export price (FOB-free on board) and the import price (CIF-cost insurance and freight). Due to the lack of data by port, in the first instance, all U.S. ports were assumed to have a similar freight rate. Similarly, the Brazilian ports were also assumed to have the same ocean freight rate. Subsequently, for the U.S. and Brazilian ports, the ocean freight rates were adjusted to the equivalent historic flow patterns for each port. Regarding the other exporting countries, similarly to the U.S. and Brazil ports case, the difference between the CIF and FOB cotton prices for trading pairs was used as a proxy for the ocean ship rate. These international cotton ocean freight rates were compiled based on the data from FAO (2011).

Efforts were made to validate the model subsequent to its construction. In particular, historic flow patterns of cotton were compared to flows associated with the base model.

Validation involved a comparison between historic export flows by U.S. and Brazilian ports and model-generated flows. Similar approach was employed in the validation of prices at different excess supply and excess demand regions. Model-projected flows were within the ranges observed at all ports for both countries for the 2008/09 MY. Likewise, the shadow prices generated by the model were found within the ranges observed at all excess supply and excess demand regions. Accordingly, the model was judged adequate for purpose of carrying out study objectives.

RESULTS

The first scenario to be analyzed was a reduction of 10 percent in ocean freight rates for vessels originating from the U.S. Gulf and South Atlantic ports to Asian and Pacific countries. The second scenario analyzed a 28 percent reduction in ocean freight rates for the same origins and destinations. Scenario three introduced a 10 percent reduction in ocean freight rates from West Coast ports to Asian and Pacific countries along with the modifications used in scenario two.

Effects on Flow Patterns and Exports

Decreasing the ocean freight rate from U.S. Gulf and Atlantic ports (Savannah, Norfolk, New Orleans, Houston, Charleston, Gulfport, and Mobile) to Asian and Pacific importing countries (China, Indonesia, Thailand, Bangladesh, Pakistan, Honk Kong, Japan, South Korea, Taiwan) due to PCE is expected to increase cotton exports via the Panama Canal. U.S. Gulf and Atlantic ports are expected to increase their share of total U.S. cotton exports. Pacific Coast ports, however, are expected to experience a reduction in exports.

A 10 percent reduction in ocean freight rates for the routes that travel via the Panama Canal causes the model to increase U.S. cotton exports via the Gulf and Atlantic ports except Gulfport, Mississippi, and Mobile, Alabama (table 1). The absolute change in exports was the largest for the port of Savannah, Georgia, followed by the port of Houston, Texas. The increase from 2,236.7 to 3,907.5 thousand bales (74.7 percent increase) in exports positioned the port of Savannah as the leading cotton exporting port passing the Long Beach – Los Angeles ports (down to 3,697.2 from 6,163.3 thousand bales). The total relative change for the U.S. Gulf and Atlantic ports was equivalent to a positive 50.5 percent, which in absolute value this is equal to an increase of 2,548.8 thousand bales.

Table 1. Estimated Change in U.S. Cotton Flows Resulting from Reducing Ocean Freight Rates due to the Panama Canal Expansion (1,000 480 lbs. bales)

Port	Base Model	Scenario 1	Change (%)	Scenario 2	Change (%)	Scenario 3	Change (%)
Savannah	2,236.7	3,907.5	74.7	4,450.9	99.0	3,903.3	74.5
Houston	1,551.8	2,046.2	31.8	2,434.5	56.9	1,795.6	15.7
New Orleans	514.7	724.2	40.7	1,197.8	132.7	1,144.7	122.4
Charleston	338.3	534.3	57.9	875.6	158.8	577.9	70.8
Norfolk	282.2	333.5	18.2	617.9	118.9	579.9	105.5
Gulfport	45.3	20.9	-54.9	20.5	-54.9	0.0	-100.0
Mobile	72.8	24.0	-67.0	0.0	-100.0	0.0	-100.0
Total U.S. Gulf and Atlantic	*5,041.8*	*7,590.6*	*50.5*	*9,597.2*	*90.3*	*8,001.4*	*58.7*
L.A.-Long Beach	6,163.3	3,697.2	-40.0	1,879.5	-69.5	3,827.7	-37.9
Oakland	343.8	343.6	-0.1	343.3	-0.1	45.4	-86.8
Total West Coast	*6,507.1*	*4,040.8*	*-37.9*	*2,222.9*	*-65.8*	*3,873.1*	*-40.4*
Laredo-El Paso	1,141.3	1,296.7	13.6	1,269.5	11.2	1,264.6	10.8
Hidalgo-Brownsville	340.6	176.6	-48.1	179.2	-47.4	179.6	-47.3
Total U.S.-Mexico Border Ports	*1,481.9*	*1,473.3*	*-0.6*	*1,448.7*	*-2.2*	*1,444.2*	*-2.5*
Total U.S. Ports	***13,030.8***	***13,104.7***	***0.6***	***13,268.8***	***1.8***	***13,318.7***	***2.2***

Note: Scenario 1 is 10 percent reduction in ocean freight rates from Gulf and Atlantic Ports. Scenario 2 is 28 percent reduction in ocean freight rates from Gulf and Atlantic Ports. Scenario 3 is Scenario 2 plus 10 percent reduction in ocean freight rates from Los Angeles-Long Beach ports.

Furthermore, the share of U.S. cotton exports through the Panama Canal increased from 38.7 percent (5,041.8 thousand bales) to 57.9 percent (7,590.6 thousand bales) after the expansion. West Coast ports decreased shipments considerably by reducing total exports approximately 2,466.3 thousand bales. The route via the intermodal option (rail to West Coast ports) reduces its share of total U.S. cotton exports by nearly 20 percentage points (from 49.9 percent to 30.8 percent). The largest decrease in exports occurs in the Long Beach – Los Angeles ports, going from 6,163.3 to 3,697.2 thousand bales, in relative terms, this is equivalent to a decline of approximately 40 percent.

As expected, cotton flow patterns resulting from the analysis of scenario two (28 percent ocean freight rate reduction) are similar to scenario one in direction, but larger in magnitude. The ports of Savannah and Houston increased cotton exports to 4,450.9 and 2,434.5 thousand bales, respectively (table 1). An important point is that the port of Houston becomes the nation's second largest cotton exporter. The ports of New Orleans, Charleston, and Norfolk more than double their exports with increases up to 158.8 percent for Charleston. Total exports from the Gulf and Atlantic ports rose to 9,597.2 thousand bales from 5,041.8 thousand bales for the base model (an increase of 90.3 percent). Such increases in exports via the Gulf and Atlantic ports indicate that the PCE could increase the canal's share in total U.S. cotton exports to 72.3 percent from 38.7 percent in the base model.

West Coast ports undergo a decline in exports, going from 6,507.1 thousand bales to 2,222.9 thousand bales. Another key observation is that the intermodal option reduces its share of total U.S. cotton exports. Only 16.7 percent of total U.S. cotton exports are shipped via the West Coast ports, which is equal to a 33.2 percentage points decrease when compared to the base model (from 49.9 percent to 16.7 percent). The largest factor for such reduction is the decrease in exports via the Long Beach – Los Angeles ports, down to 1,879.5 thousand bales which places LA-LB as the third most important port for the U.S. cotton exports (behind the ports of Savannah and Houston).

In scenario 3, after introducing the 10 reduction in ocean freight rates from the ports of Los Angeles-Long Beach, the ports of Savannah and Houston both lose competitiveness when compared to scenario two but their export levels were very similar to scenario one. The main reason is that the increase in competitiveness by the Los Angeles-Long Beach ports attracts more shipments as their exports go to 3,827.7 thousand bales, which is greater than the results under both scenarios one and two. However, when contrasted to the base model, the total exports from the West Coast ports are still lower than the base model (decrease of 40.4 percent). It is interesting to note that the Oakland port also loses competitiveness to their Californian counterpart as its exports are reduced to 45.4 thousand bales (a negative 86.8 percent relative change). Overall, similarly to the other two scenarios, the participation of the U.S. Gulf and Atlantic ports is expected to increase (positive 58.7 percent), with the port of Savannah as the top cotton exporting port.

Although cotton flows are altered with lower ocean freights for the Atlantic and Gulf ports, total U.S. cotton exports are only modestly impacted. For the 10 percent freight rate reduction scenario, the increase in total U.S. cotton exports were equal to 73.9 thousand bales which is equivalent to a 0.6 percent increase (table 1). As for the second scenario (28 percent reduction), a greater reduction in ocean freight rates increased total U.S. cotton exports. But this also causes only a modest increase in relative terms (1.8 percent), with total U.S. cotton exports rising to 13,268.8 thousand bales, up by 238.0 thousand bales. The largest increase in total U.S. exports is found in scenario three. This result was expected since with more competition between ports, the cotton exporting agents gain the most as they have less costly shipping options. The total cotton exports for this scenario was equal to 13,318.7 thousand bales, which is equal to a growth of 287.9 thousand bales when compared to the base model (2.2 percent increase).

U.S. Warehouse Prices and Revenues

As the PCE occurs, there would be an anticipated reduction in ocean freight rates which corresponds to a decrease in transportation costs linking the U.S. producers (warehouse level) to importers in the Asian and Pacific importing countries. This increases price and production in U.S. regions that ship via the Panama Canal. For example, in scenario one, U.S. cotton-producing regions that ship via the Panama Canal experience an increase in price that ranges from $2.95/bale (Texas) to $7.41/bale (Georgia) (table 2). Most of the U.S. cotton production regions experienced an increase in price. However, in scenario one, the states of Arizona, California and Oklahoma undergo prices decrease as the PCE occurs. Prices decreased modestly for those U.S. regions since exports are diverted to Asian and Pacific importing countries via the West Coast ports.

Table 2. Estimated Annual Increase in U.S. Cotton Warehouse Revenues (million dollars) and Warehouse Price ($/bale) Resulting from Reduction in Ocean Freight Rates due to Panama Canal Expansion

State	Scenario 1		Scenario 2		Scenario 3	
	Revenue	Price	Revenue	Price	Revenue	Price
Texas	$22.37	$2.95	$85.73	$11.42	$109.76	$14.04
Georgia	$15.56	$7.41	$44.46	$21.03	$45.22	$21.39
Tennessee	$13.43	$6.31	$42.31	$19.68	$43.22	$20.15
Arkansas	$9.73	$5.99	$30.04	$18.36	$31.67	$19.35
Mississippi	$7.26	$6.39	$21.78	$18.99	$22.19	$19.35
North Carolina	$7.05	$6.51	$23.84	$21.78	$23.58	$21.56
Missouri	$4.45	$5.70	$13.61	$17.32	$13.61	$19.01
South Carolina	$3.67	$7.40	$11.29	$22.60	$11.09	$22.18
Louisiana	$3.16	$6.78	$8.83	$18.82	$9.02	$19.22
Alabama	$2.84	$5.43	$8.79	$16.66	$9.33	$17.70
Virginia	$1.25	$5.94	$4.64	$21.89	$4.62	$21.81
Florida	$0.55	$7.23	$1.58	$20.69	$1.61	$21.11
New Mexico	$0.22	$4.73	$0.78	$16.26	$0.87	$18.04
Kansas	$0.05	$5.70	$0.14	$17.27	$0.15	$19.01
Oklahoma	$0.01	$(0.03)	$3.12	$11.78	$3.25	$12.28
Arizona	$(0.13)	$(0.29)	$(0.45)	$(1.00)	$2.99	$6.65
California	$(0.31)	$(0.26)	$(1.14)	$(0.94)	$4.78	$3.61
U.S. Total	***$91.15***	***$4.93***	***$299.36***	***$16.04***	***$336.97***	***$17.44***

Note: Scenario 1 is 10 percent reduction in ocean freight rates from Gulf and Atlantic Ports. Scenario 2 is 28 percent reduction in ocean freight rates from Gulf and Atlantic Ports. Scenario 3 is Scenario 2 plus 10 percent reduction in ocean freight rates from Los Angeles-Long Beach ports.

As noted in table 2, the state with the largest gain in revenue due to the PCE was Texas. For scenario one, the increase in warehouse revenues for that state was equal to $22.37 million. Taking into account the relatively small change in price that occurs in Texas ($2.95/bale) when compared to the other states, the main reason for such increase in warehouse revenue is the an expansion of cotton production[6]. Georgia and Tennessee had significant gains in warehouse revenues as well with $15.56 million and $13.43 million, respectively. The gain for Georgia is relevant to discuss since the port of Savannah is located in that state and local cotton warehouses were the beneficiaries of this expansion. Although the impacts were relatively small, as expected, the states that depend heavily on West Coast ports experienced a decline in warehouse revenues (Arizona, California and Oklahoma).

Figure 1 below shows the change in producer (warehouse level) revenue by crop reporting districts (CRD). Due to its large producing area, the state of Texas accrues the most benefits of the canal expansion whereas the gains in warehouse revenue ranged from $0.12 million (CRD number 81, Kennedy county area) to $5.54 million (CRD number 12, Lubbock county area). The state of Georgia comes in second as the CRDs of number 80 (Brooks county area) and 70 (Lee county area) increased their warehouse revenue by $6.49 and $5.14 million, respectively. With a gain of $11.96 million, the CRD of number 10, located in the state of Tennessee (Memphis area), is indicated as the largest beneficiary with respect to warehouse revenue. As it was expected, although relatively small losses, the CRDs located in the state of California is shown to reduce their warehouse revenues.

[6] According to NASS (2011), cotton production for the state of Texas was approximately 6.3 million bales for the 2008/09 market year, which represented 40 percent of U.S. production.

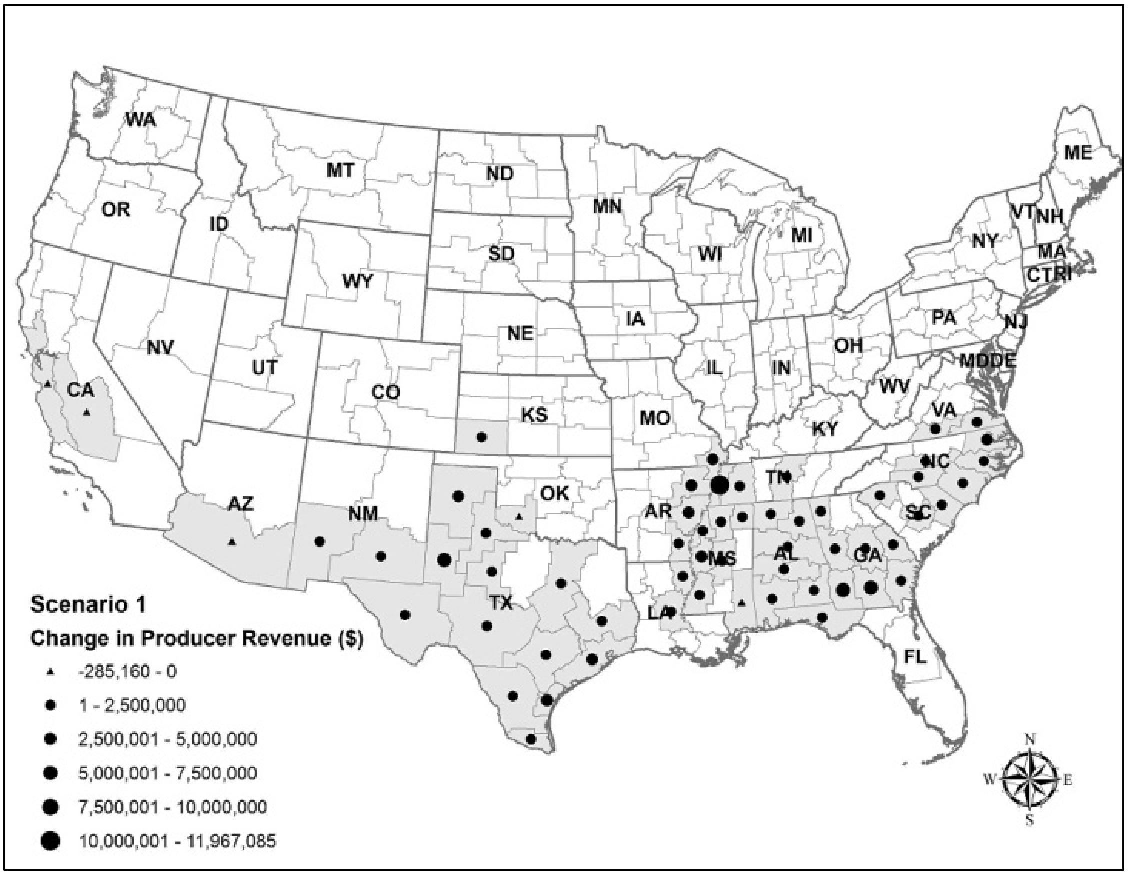

Figure 1. Model-estimated changes in cotton producer (warehouse level) revenues by crop reporting districts for scenario 1
Note: Scenario 1 is 10 percent reduction in ocean freight rates from Gulf and Atlantic Ports.

In scenario two, the 28 percent reduction in ocean freight rates from Gulf and Atlantic ports to Asian and Pacific markets is estimated to increase annual warehouse revenues for all cotton producing states except California and Arizona (table 2). The state with the largest gain is Texas, with an increase in warehouse revenue equal to $85.73 million. As discussed earlier, Texas is a special case since most of the gain in revenue is due to increased cotton production (up 69.6 thousand bales) and not higher prices. Other states underwent a larger increase in price, but there was less impact on warehouse revenues. For example, with respect to prices, cotton warehouses in South Carolina and Virginia were the greatest beneficiaries of higher prices attributed to the PCE, with increases of $22.60/bale and $21.89/bale, respectively. However, because production in those two states is relatively small compared to the others, warehouse revenues were less when compared to Texas and Georgia. Cotton warehouses in Oklahoma accrue gains in warehouse revenues rather than losses. This occurs because part of the Oklahoma cotton shipments were routed via the port of Houston rather than the intermodal route. Revenue losses to warehouses in California were estimated at $1.14 million which is relatively small when compared to the gains by other states.

As figure 2 below indicates, the CRDs located in the state of Texas followed by the states of Georgia and Tennessee experience the largest increases in revenues as cotton is mostly shipped through the ports located in the Gulf and East Atlantic. For the state of Texas, the CRD of number 12 (Lubbock area) is shown to gain the most for that state as its revenue increases

$21.3 million. As in scenario one, the CRDs of number 80 (Brooks county area) and 70 (Lee county area) in the state of Georgia represent most of the increase for that state as their revenue increase by $18.64 and $14.1 million, respectively. Similarly to scenario one, for the state of Tennessee, the CRD of number 10 (Memphis area) is the largest gainer of the canal expansion, with a warehouse revenue increase of $37.83 million. As for the CRDs located in California and Arizona, the decreases in warehouse revenue were projected to be greater than the estimates from scenario one; however, the estimated losses in warehouse revenues (less than $1.2 million) were comparatively lower than the gains in other states.

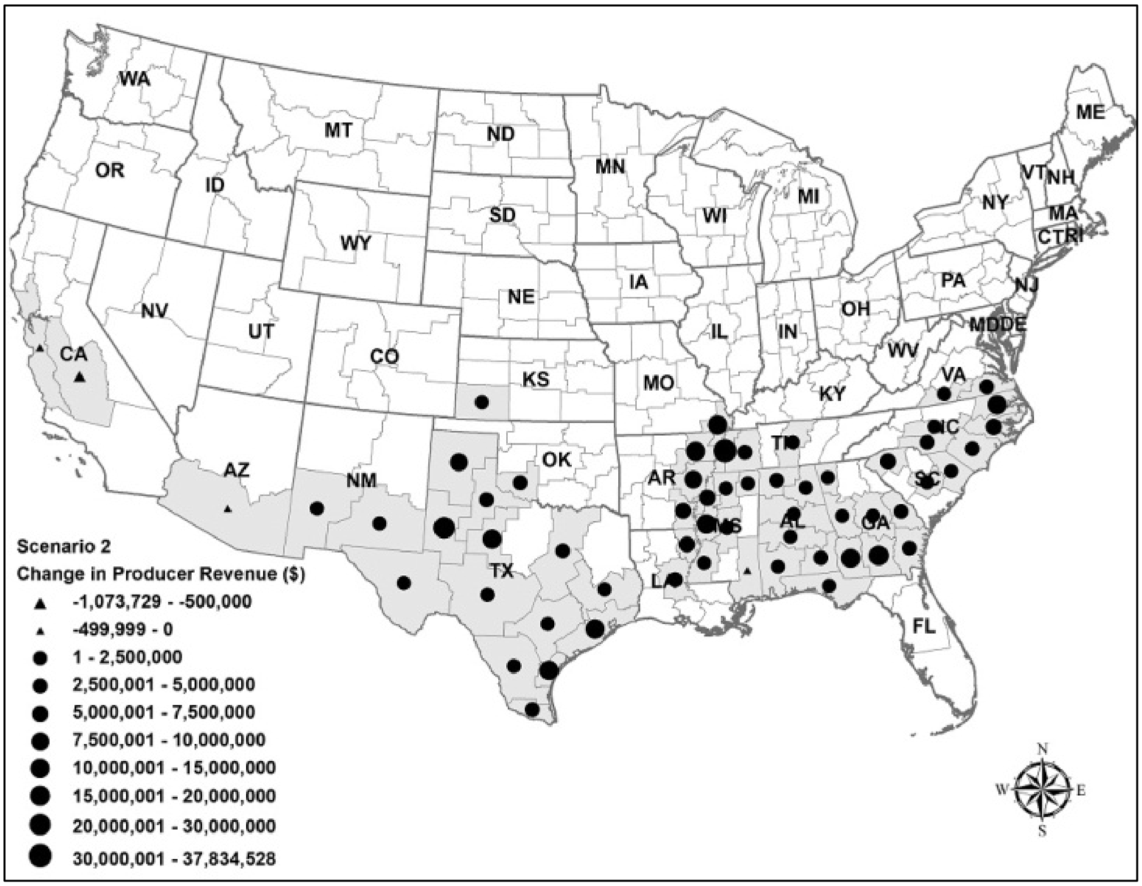

Figure 2. Model-estimated changes in cotton producer (warehouse level) revenues by crop reporting districts for scenario 2

Note: Scenario 2 is 28 percent reduction in ocean freight rates from Gulf and Atlantic Ports.

Scenario three indicates that Texas is the state with the largest increase in warehouse revenue (table 2). With the 10 percent reduction in ocean freight rates from the Los Angeles-Long Beach ports to Asian countries, the state of Texas is shown to have a significant increase in gains when compared to other states. With an increase in warehouse revenue of $109.76 million, this represents a 28.0 percent greater gain (up $24.03 million) than the gains estimated in scenario two ($85.73 million). On the other hand, when compared to scenario two, the increases in warehouse revenue for the states of Georgia and Tennessee were only $0.76 and $0.91 million, respectively. This indicates that both the PCE and improvements in the Los Angeles-Long Beach ports would substantially enhance the exporting cotton industry of Texas. In contrast to the other two scenarios, all states were shown to have an increase in warehouse revenue. The states of Arizona and California had increases in warehouse revenue of $2.99 and 4.78 million, respectively.

Similarly to the previous two scenarios, the CRDs located in the state of Texas followed by the states of Georgia and Tennessee experience the largest increases in revenues (figure 3). For the state of Texas, the CRD of number 12 (Lubbock area) is shown to increase its warehouse revenue by $39.03 million, which makes it the largest gain in the nation passing the CRD of number 10 in Tennessee. The increase in warehouse revenue for the CRD 10 (Memphis area) was only $0.12 million greater than the gains from scenario two (from $37.83 to $37.95 million). As in scenario one and two, the CRDs of number 80 (Brooks county area) and 70 (Lee county area) in the state of Georgia represent most of the increase for that state as their revenue increase by $18.96 and $15.04 million, respectively. As previously mentioned, in contrast to the other two scenarios, the states of Arizona and California are presented to have net increases in warehouse revenue.

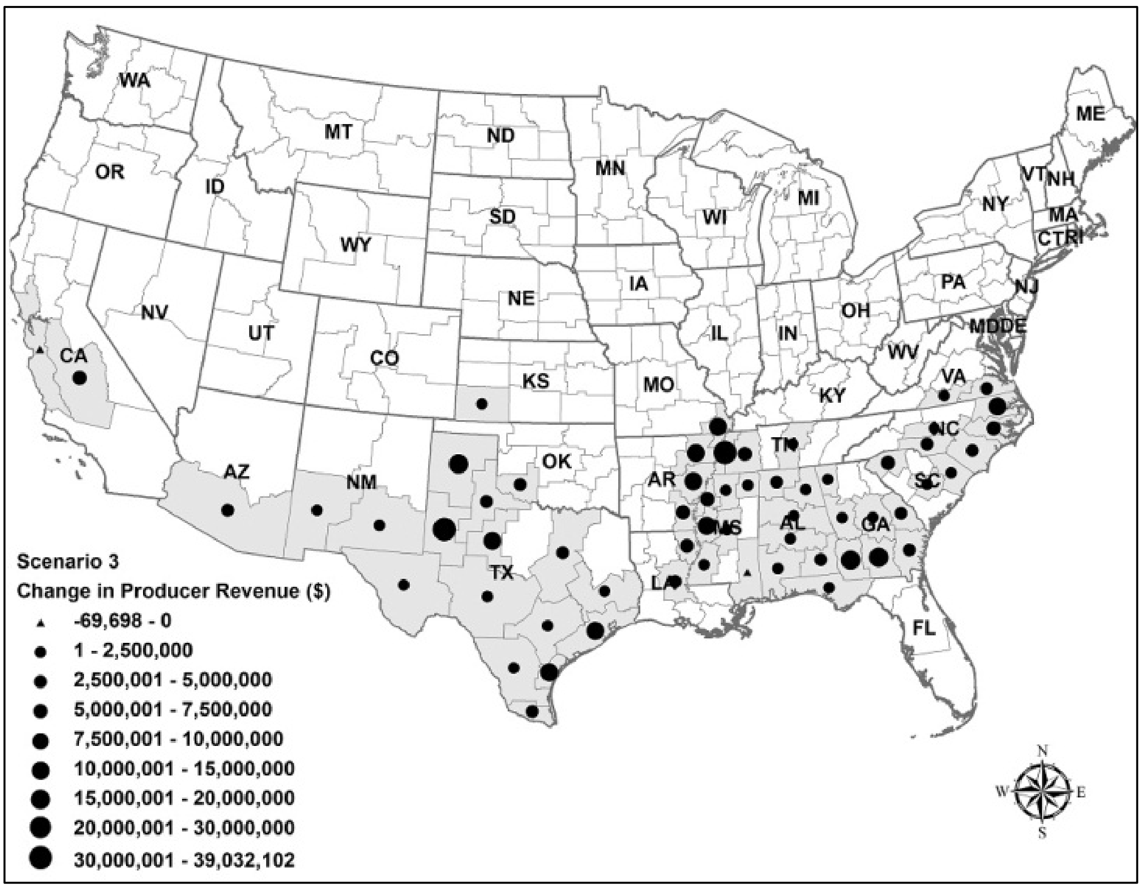

Figure 3. Model-estimated changes in cotton producer (warehouse level) revenues by crop reporting districts for scenario 3

Note: Scenario 3 is Scenario 2 plus 10 percent reduction in ocean freight rates from Los Angeles-Long Beach ports.

As table 2 shows, the warehouse revenue for U.S. cotton increased for all scenarios. A 10 percent reduction in ocean freight rates from Gulf and Atlantic ports to Asian and Pacific importing countries is projected to increase annual cotton warehouse revenues by approximately

$91.15 million. In relative terms, for this scenario, the total increase in warehouse revenue for the U.S. is equal to 2.21 percent. For scenario two, the 28 percent rate reduction causes a greater positive impact on the warehouse revenue for the U.S. The revenue gains to cotton warehouses are larger when the savings in cost due to the PCE is fully considered. Hence, the total increase in U.S. cotton warehouse revenue is equal to $299.36 million, which, in relative terms, is equivalent to an increase of 7.27 percent. Overall, the largest gain in warehouse revenue for the entire country takes place in scenario three. As it was expected, as both the Los Angeles-Long Beach ports and Gulf and Atlantic ports enhance their competitiveness to export cotton, the total increase in warehouse revenue is equal to $336.97 million, which is, in relative terms, a rise of 8.19 percent.

U.S. Cotton Competitiveness in the World Market

The impact of the PCE on the competitiveness of exporting countries is evaluated with the focus on exports, prices, and revenue. Table 3 presents the results of the scenarios that were analyzed. All scenarios indicate that India, Brazil, Sub-Sahara Africa, Uzbekistan and the Rest of the World Exporters experience lower exports, prices, and revenues attributed to PCE. Among these countries/regions, the Rest of the World Exporters were the most affected. Individual and large cotton exporting competitors, such as Brazil and India, lose competitiveness in global cotton trade and losses occur within the national industries. For example, in scenario three, exports, price, and producer revenue in Brazil are estimated to decrease by 37.76 thousand bales, $1.39/bale, and $12.36 million, respectively. However, for all analyzed scenarios, these losses in exports, prices, and revenues are very modest in relative terms. For example, in scenario three, Brazilian exports, price, and revenue are reduced by 1.46, 0.59, and 2.04 percent, respectively.

Table 3. Estimated Effects of Panama Canal Expansion on Exports, Prices, and Revenue for Selected Exporting Countries

Exports (1,000 480 lbs. bales)	Scenario 1	Scenario 2	Scenario 3
United States	73.90	238.00	287.90
India	-9.14	-30.38	-36.91
Brazil	-10.71	-29.02	-37.76
Australia	-0.60	-1.92	-2.33
Sub-Sahara Africa	-2.26	-7.51	-9.13
Uzbekistan	-1.94	-6.44	-7.83
Rest of the World	-9.32	-30.96	-37.62
Prices ($/bale)	Scenario 1	Scenario 2	Scenario 3
United States	$4.93	$16.04	$17.44
India	($0.29)	($0.96)	($1.16)
Brazil	($0.40)	($1.07)	($1.39)
Australia	($0.29)	($0.96)	($1.16)
Sub-Sahara Africa	($0.29)	($0.96)	($1.16)
Uzbekistan	($0.29)	($0.96)	($1.16)
Rest of the World	($0.29)	($0.96)	($1.16)
Revenues (million $)	Scenario 1	Scenario 2	Scenario 3
United States	$91.15	$299.36	$336.97
India	($3.48)	($11.54)	($14.00)
Brazil	($3.53)	($9.51)	($12.36)
Australia	($0.54)	($1.81)	($2.19)
Sub-Sahara Africa	($1.60)	($5.30)	($6.42)
Uzbekistan	($1.34)	($4.45)	($5.38)
Rest of the World	($3.82)	($12.68)	($15.37)

Note: Scenario 1 is 10 percent reduction in ocean freight rates from Gulf and Atlantic Ports. Scenario 2 is 28 percent reduction in ocean freight rates from Gulf and Atlantic Ports. Scenario 3 is Scenario 2 plus 10 percent reduction in ocean freight rates from Los Angeles-Long Beach ports.

Due to the PCE and its potential reduction in ocean freight rates for the Gulf and Atlantic ports to Asian and Pacific markets, the U.S. gains competitiveness through increases in exports, prices, and warehouse revenue (table 3). For scenarios one and two, the increase in exports is equal to 73.90 and 238.00 thousand bales, respectively. Cotton price and warehouse revenues also increase in both scenarios. There are greater impacts from scenario two due to the larger reduction in ocean freight rates. With a 28 percent reduction in ocean freight rates, the cotton price and warehouse revenue increase to $16.04/bale and $299.36 million, respectively. Nonetheless, the cotton exporting industry of the U.S. is better off in scenario three. As the Los Angeles-Long Beach ports improve their efficiency to compete with the Gulf and Atlantic ports, exports, price, and warehouse revenue in the U.S. are estimated to increase by 287.90 thousand bales, $17.44/bale, and $336.97 million, respectively.

CONCLUSIONS

By 2014, the Panama Canal Authority is expected to complete expansion of the canal. U.S. cotton producers are expected to benefit economically from PCE since the expansion will reduce ocean freight rates along routes for selected U.S. ports (Gulf and Atlantic ports) to final destinations in Asian and Pacific importing countries. A spatial price equilibrium model of the international cotton sector was developed and used to evaluate the effects of the PCE.

Three scenarios were analyzed: (i) 10 percent reduction in ocean freight rates from shipments originated in the U.S. Gulf and Atlantic ports with final destination the Asian and Pacific importing countries; (ii) 28 percent reduction in ocean freight rates for scenario one; and (iii) scenario two plus 10 percent reduction in ocean freight rates from Los Angeles-Long Beach ports to Asian and Pacific importing countries. For the 10 percent reduction scenario, the cotton flows and exports had substantial changes. Cotton exports to Gulf and Atlantic ports increased 50.5 percent with the port of Savannah leading the way with an increase of 74.7 percent. The Long Beach – Los Angeles ports decreased its participation in total U.S. cotton exports considerably, down almost 40 percent. Overall, in scenario one, the percentage of U.S. cotton exports via the Panama Canal relative to the total U.S. cotton exports increased from 38.68 to 57.88 percent. Further, total U.S. cotton exports are expected to increase by 73.9 thousand bales, which is equivalent to a 0.6 percent rise. A 10 percent reduction in ocean freight rates caused by the PCE is projected to annually increase revenues of U.S. cotton warehouses by $91.15 million, with the state of Texas accruing the most gains ($22.37 million) followed by the states of Georgia ($15.56 million) and Tennessee ($13.43 million). With respect to the world cotton trade, the modest increase in exports due to the PCE made the U.S. cotton industry more competitive. On the other hand, all competing export countries had very modest decreases in their exports as well as prices and revenues with individual countries such as Brazil and India experiencing the largest reduction.

The 28 percent ocean freight rate reduction results in a 90.3 percent increase in exports through the U.S. Gulf and Atlantic ports. The largest recipient for this increase is the port of Savannah. Exports increased from 2,236.7 thousand bales to 4,550.9 thousand bales annually. Interesting to note that in this scenario the port of Houston (2,434.5 thousand bales) passes the ports of Long Beach – Los Angeles (1,879.5 thousand bales) in cotton exports and becomes the second largest exporter. Taking into account all these changes, the participation of the Panama Canal as an exporting route increased; the percentage of U.S. cotton exports via the Panama Canal relative to the total U.S. cotton exports increased from 38.68 to 72.31 percent. On the other hand, the rail to West Coast ports route decreased its percentage relative to the total U.S. cotton exports to 14.16 percent.

As it is assumed that the ports of Long Beach – Los Angeles will take action and improve their competitiveness, a scenario is analyzed by introducing a 10 percent reduction in ocean freights from these ports to importing countries in Asia. Estimates of this scenario indicated that the ports of Savannah and Houston both lose competitiveness when compared to scenario two but their export levels were very similar to scenario one. However, when contrasted to the base model, the total exports from the West Coast ports are still lower than the base model (decrease of 40.4 percent). Overall, similarly to the other two scenarios, the participation of the U.S. Gulf and Atlantic ports is expected to increase (positive 58.7 percent), with the port of Savannah as the top cotton exporting port.

As expected, the total expected reduction scenario (28 percent) is projected to annually increase revenues of U.S. cotton warehouses by $299.36 million, an increase of 7.27 percent. Similarly to scenario one, the states of Texas ($85 million), Georgia ($44 million) and Tennessee ($42 million) are the greatest recipients of the expansion with respect to warehouse revenues. Additionally, the U.S. total cotton exports increase 238 thousand bales, which in relative terms is equal to a 1.8 percent rise. As for the scenario where the ports of Los Angeles-Long Beach improve their efficiency, with a rise of $336.97 million (up 8.19 percent) and 287.9 thousand bales (up 2.2 percent), respectively, the U.S. cotton warehouses are shown to benefit the most as the ports compete with each other. On the other hand, in all scenarios, all the competing exporting countries accrue decreases in exports, prices, and revenues.

In summary, the expansion of the Panama Canal is important for U.S. cotton exports. As the expansion is completed, the analysis indicates a shift in U.S. cotton export flows from West Coast ports to Gulf and Atlantic ports as well as an increase in exports and warehouse revenues. In addition, this study suggests that West Coast ports may not face large economic losses due to the canal expansion if improvements are implemented to increase the efficiency of these ports. As for other competing exporting countries, modest declines in exports, prices, and revenues are expected to occur.

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APPENDIX

Mathematical Representation of the Model

A spatial equilibrium model was developed that uses quadratic programming to maximize producers' and consumers' surplus. Given linear supply and demand equations for all regions, the objective function and balance restrictions are expressed as:

$$(1)\ \text{Max NW}=\{\sum_q\{-\sum_i\left(\alpha_{iq}+0.5\beta_{iq}S_{iq}\right)S_{iq}-\sum_b\left(\alpha_{bq}+0.5\beta_{bq}S_{bq}\right)S_{bq}$$

$$-\sum_f\left(\alpha_{fq}+0.5\beta_{fq}S_{fq}\right)S_{fq}+\sum_j\left(\alpha_{jq}-0.5\beta_{jq}D_{jq}\right)D_{jq}$$

$$+\sum_l\left(\alpha_{lq}-0.5\beta_{lq}D_{lq}\right)D_{lq}+\sum_d\left(\alpha_{dq}-0.5\beta_{dq}D_{dq}\right)D_{dq}\}$$

$$-\{\sum_m(\sum_i(\sum_r C_{irm}T_{irqm}+\sum_p C_{ipm}T_{ipqm}+\sum_j C_{ijm}T_{ijqm})$$

$$+(\sum_b(\sum_z C_{bzm}T_{bzqm}+\sum_l C_{blm}T_{blqm}))\}$$

$$-\sum_r(\sum_p C_{rpq}T_{rpq})-\sum_d(\sum_p C_{pdq}T_{pdq}+\sum_z C_{zdq}T_{zdq}+\sum_f C_{fdq}T_{fdq})\ \}$$

subject to:

(2)$\sum_m(\sum_j T_{ijqm}+\sum_r T_{irqm}+\sum_p T_{ipqm})+G_{qq+1}\leq S_{iq}+G_{q-1q}$ for all i and q;

(3)$\sum_m(\sum_l T_{blqm}+\sum_z T_{bzqm})+H_{qq+1}\leq S_{bq}+H_{q-1q}$ for all b and q;

(4) $\sum_p T_{rpq}\leq\sum_i\sum_m T_{irqm}$ for all r and q;

(5) $\sum_d T_{pdq}\leq\sum_i\sum_m T_{ipmq}+\sum_r T_{rpq}$ for all p and q;

(6) $\sum_d T_{zdq}\leq\sum_b\sum_m T_{bzmq}$ for all z and q;

(7) $\sum_m\sum_i T_{ijqm}\geq D_{jq}$ for all j and q;

(8) $\sum_m\sum_b T_{blqm}\geq D_{lq}$ for all l and q;

(9) $\sum_p T_{pdq}+\sum_z T_{zdq}+\sum_f T_{fdq}\geq D_{dq}$ for all d and q;

(10) $\sum_d T_{fdq}+R_{qq+1}\leq S_{fq}+R_{qq-1}$ for all f and q;

(11) $\sum_p T_{pd}\leq PC_p$ for all p;

(12) $\sum_z T_{zd}\leq PC_z$ for all z;

(13) $T,S,D\geq 0$ for all i, b, j, l, f, q, d, r, p, and z;

where equation (1) is the net welfare interpreted as consumer surplus plus producer surplus minus cotton handling, storage, and transportation costs. Equations (2) to (6) are supply balance constraints. Equation (2) constrains the cotton flow from ith (U.S.) excess supply region to all receiving and transhipment points in each quarter to be less than or equal to the quantity supplied or carried over by the supply region i. Similarly, equation (3) constrains quantity supplied or carried-over from each excess supply region b (Brazil) to all excess demand (l) and port (z) locations to be less than or equal to quantity supplied or carried over. Equation (4) limits transhipments at U.S. rail-loading location so that the quantity shipped from each location is less than or equal to total quantities received from all U.S. supply regions for every quarter. Equation (5) balances the inflow and outflow of cotton at each U.S. port in each quarter. Similarly, equation (6) constrains shipments from Brazilian ports (z) to foreign importing countries (d).

Equations (7) to (9) are demand balance constraints. Equation (7) limits quantity shipped by different inland modes to each U.S. demand location (j) to be at least equal to or greater than the quantity demanded for every quarter of the year. Equation (8) constrains quantity shipped by truck to each Brazilian demand location (l) to be at least equal to or greater than the quantity demanded for every quarter of the year. Equation (9) constrains quantity imported by each importing country (d) to be at least equal to or greater than the quantity demanded for each quarter. Equation (10) limits quantity shipped from exporters (f) to all importing countries (d) to be less than or equal to the quantity supplied at f for all quarters of the year. Equations (11) and (12) impose shipping capacity limits. Equation (11) constrains cotton exports by U.S. port to be less than or equal to its capacity. Equation (12) constrains cotton exports by Brazilian port to be less than or equal to its capacity. Equation (13) represents the non-negativity conditions. Table A1 shows the subscripts, parameters, and variables included in the formulated model.

Table A1. Subscripts, Parameters and Variables Included in Formulated Model

Subscripts	***Definition (quantity)***
Q	quarter (1,2,3,4)
I	U.S. excess supply locations (1,2,3…410)
B	Brazil excess supply locations (1,2,3…152)
F	foreign exporting regions (1,2,3…5)
J	U.S. excess demand locations (1,2,3…11)
L	Brazil excess demand locations (1,2,3…21)
D	Foreign importing countries (1,2,3…14)
M	Inland modes of transportation (1,2,3,4)
R	Rail-loading terminal (1,2,3…5)
P	U.S. ports (1,2,3…15)
Z	Brazil ports (1,2,3,4,5)
Parameters	***Definition***
C	Transportation costs per 480 lb bales by the various modes
Variables	***Definition***
S_i	U.S. excess supply regions
S_b	Brazil excess supply regions
S_f	Foreign excess supply regions
D_j	U.S. excess demand regions
D_l	Brazil excess demand regions
D_d	Foreign excess demand regions
T	Cotton flow in 480 lb bales between nodes
G	Quarterly quantities stored in U.S.
H	Quarterly quantities stored in Brazil
R	Quarterly quantities stored in other major exporting countries
PC	Port capacity