THE IMPACT OF THE PANAMA CANAL EXPANSION ON U.S. SOYBEAN EXPORTS

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

The objective of this study was to evaluate the impact of the Panama Canal Expansion on the flow of soybeans from producing regions in the U.S. to its ports for export. Specific objectives of this study were to determine the toll rate at which the Panama Canal Authority will maximize their toll revenues for soybeans transiting the canal, and to analyze the impact of the canal expansion on soybean shipments from U.S. producing regions to ports for export.

To conduct this study a spatial optimization model was developed. The model minimizes all transportation costs associated with the transportation of soybeans. Major findings were that the expansion of the Panama Canal will increase shipments out of the Gulf through the canal, and reduce the overall costs of shipping by 5 percent. Domestic transportation proved to be somewhat insensitive to changes in the toll rate.

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CHAPTER 1. INTRODUCTION

The Panama Canal Authority announced in 2006 that the existing canal system is going to be expanded. This Panama Canal expansion (PCE) is expected to be complete by 2015, with a total project cost of 5.25 billion dollars (Panama Canal Authority, October 2012). The Panama Canal Authority has already sued contracts for 4.25 billion dollars for dredging and the building of the new locks. This expansion will in essence double the capacity of the Panama Canal. Figure 1.1 shows the amount of tons as well as the number of transits that the Panama Canal has handled over the last 14 years. The number of transits has stayed relatively consistent while the tonnage shipped through the canal has continued to increase.

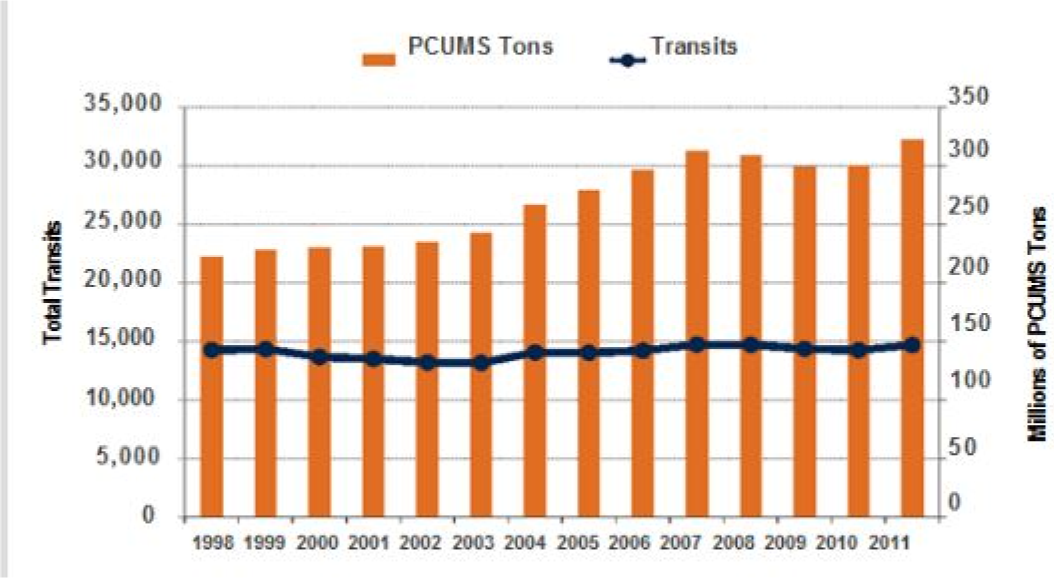


Figure 1.1. Canal Utilization 1998 to 2011. Source: U.S. DOT Maritime Administration, 2013.

The Panama Canal is the major shipping route from the U.S. Gulf and Eastern ports, to the East Asian market, which includes countries such as; Japan, China, South Korea, and Taiwan. These countries as well as other Asian markets account for a large majority of U.S. soybean exports. The vast production of U.S. soybeans is concentrated close to the Mississippi river and areas that are geographically closer to the U.S. gulf ports rather than those ports on the western coast of the U.S. The model developed for this study was created to determine the effects and sensitivity of the transportation of U.S. soybeans due to changes in the Panama Canal.

Need for Study

Dredging is a large part of the expansion program and will allow the post-Panamax vessels to transit the canal. The new locks will be 11.5 meters wider, 5.5 meters deeper, and 122.2 meters longer than the existing locks (Panama Canal Authority, October 2012). These larger locks along with the deeper dredged canal will allow the post-Panamax ships to navigate the Panama Canal safely. Post-Panamax vessels can carry up to 12,000 TEUs (twenty-foot equivalent unit) of cargo compared to Panamax vessels, which can carry only around 5,000 TEUs and is essentially doubling the handling capacity of the canal. The expansion is necessary to accommodate growing trade volume and to release congestions, but also to handle post-Panamax vessels, which have increased significantly in number for the last decade. Many believe that this will then reduce shipping costs (Sawyer, 2013), (Dengo, 2012). Drewry Supply Chain Consultants a maritime industry research firm, projects the Panama Canal could seize up to 25 percent of the traffic coming into the west coast due to the expansion, and head instead to the gulf and east coast ports directly (Costa & Rosson, 2012). According to Rodrigue (2010), a standard Panamax container ship has annual operating costs of $2,314/TEU, while post-Panamax vessels have the potential to reduce annual operating costs by up to $1,450/TEU. He also believes that the expansion of the Panama Canal will enable maritime shippers to reduce all-water costs by approximately 37 percent (Rodrigue, 2010).

The expansion will have a significant impact on agricultural shipments to Asian countries, including China, Japan, and South Korea. In addition, there will be significant changes in domestic flows of agricultural commodities from producing regions to ports for export. Soybeans being one of the largest commodities imported by the Asian markets, it is important to determine the most efficient way of transporting soybeans from the producers in exporting countries to the consumers in importing countries. This is important because the Panama Canal is a gateway for shipping U.S. soybeans to Asia as it saves time and money. A study states that "for cargo shipped from the U.S. East Coast to Asia, for instance, the canal saves about ten days' sailing time" (Moon & Koo, 2006).

Objectives

The objective of this study is to evaluate the impact of the Panama Canal Expansion on the U.S. flow of soybeans from producing regions in the U.S. to its ports for export, with special interest in the flow of soybeans to the East Asian market. East Asia has a large demand for the import of soybeans, and with the growth of China a large majority of U.S. soybeans end up being shipped to East Asia. With this being said, the area of interest will be whether more U.S. soybeans will be shipped to the U.S. gulf ports and through the Panama Canal to get to East Asia or will soybeans be shipped to the U.S. West coast ports such as the Pacific Northwest (PNW) or will Brazil capture the U.S.'s soybean shipments to East Asia. In addition, the study will investigate the potential impact of the PCE on the transportation costs of soybeans before and after the PCE.

The commodity chosen for this study is soybeans because they are highly demanded in the East Asian market where they are not able to grow enough soybeans for domestic consumption alone. Soybeans are also chosen because they are one of the largest volume commodities traded internationally along with the fact that U.S. produces between 40 and 50 percent of all soybean exports. The global total of corn and soybean imports in 2011 was 93 and 88 million metric tons (mmt), respectively. When compared to rice and barley imports that totaled 32mmt, and just under 18 mmt, which is a much smaller scale of grain trade than soybeans. Lastly, soybeans are a commodity that would be greatly affected by changes in the Panama Canal because close to 60 percent of U.S. soybean exports leave through the gulf.

Table 1.1. World Production and Exports for Selected Crops. Source: NASS.

Commodity	Attribute	Country	2009/2010	2010/2011	2011/2012	2012/2013
Barley	Production (1000 MT)	World	151,077	123,140	133,543	130,017
	Exports (1000 MT)	World	17,140	15,931	20,392	19,608
Corn	Production (1000 MT)	World	825,566	835,919	889,327	868,796
	Exports (1000 MT)	World	96,644	91,259	116,980	95,207
Oilseed, Soybean	Production (1000 MT)	World	260,600	264,145	239,525	267,853
	Exports (1000 MT)	World	91,440	91,700	92,151	100,648
Rice, Milled	Production (1000 MT)	World	440,947	449,946	466,920	471,596
	Exports (1000 MT)	World	31,359	35,182	39,885	39,476

To evaluate the impact of the PCE on the production and flow of soybeans a comparative analysis will be done by looking at soybean trade pre-PCE compared to after the PCE. There is a special interest in the toll rate, because the Panama Canal Authority has not set toll rates for post-PCE. Developing a base-case model and a PCE model to compare the effects the PCE will have on the overall transportation costs. Then changing the toll rate at the Panama Canal to evaluate the change of soybeans shipped through the Panama Canal as well as those that ship elsewhere.

Methods

A spatial optimization model based on a linear programming algorithm will be developed for the study. The model includes the U.S., Brazil, and Argentina as the major exporting countries, and 14 importing regions, which include major importing countries such as China, Japan, South Korea, and various European countries. The model also has 11domestic consumption regions within the U.S. based largely upon soybean crushing locations.

The objective function of the model is to minimize domestic and ocean transportation costs in shipping soybeans from producing regions in the U.S., Brazil, and Argentina to importing countries. The objective function is optimized subject to a set of linear constraints.

Organization

The overview of the Panama Canal is briefly reviewed in Chapter 2. A collection of literature has been published on spatial optimization and general equilibrium models that involve the transportation of agricultural commodities, as well as those commodities being transported through the Panama Canal. Some of these studies are reviewed in Chapter 3. Methodology used for this study is examined in Chapter 4. Chapter 5 reveals the findings of transportation costs and the flow of soybeans from the U.S., Brazil, and Argentina to its trading partners, and evaluates the impact of the Panama Canal expansion on the movements of soybeans. Chapter 6 presents the summary and conclusions.

CHAPTER 2. OVERVIEW OF THE PANAMA CANAL

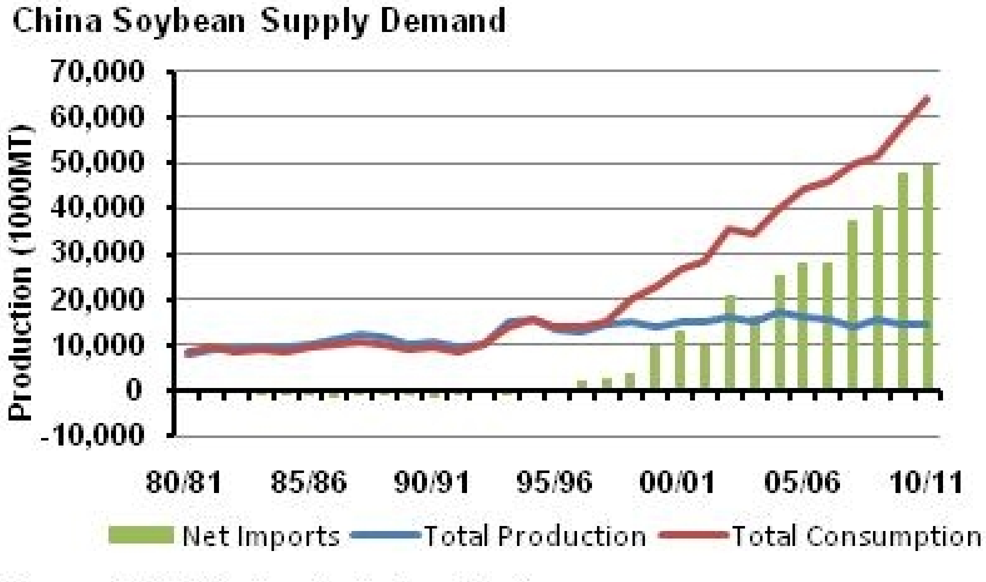
The United States purchased the rights to construct a canal through Panama for $40 million from the French Canal Company in 1903 (Eriksen, 2000). It took 10 years and $387 million before the canal opened in 1914. This shortcut has become a major benefit to world trade between the Atlantic and Pacific Oceans, where as it used to be a 12,000 mile journey around Cape Horn to get from one ocean to the other. The U.S. retained operational control of the Panama Canal as the Panama Canal Commission from 1979 until 1999 when the canal was then signed over as the Panama Canal Authority, which still act as the operators today. The difference between these operators is that the U.S. operated as a non-profit on a break-even basis, while the Panama Canal Authority is operating autonomously as a for-profit business. Meaning that the Panama Canal Authority are trying to maximize their revenues, which could lead to various changes in toll rates for transiting the Panama Canal especially after the expansion is completed.

Table 2.1. Agricultural Commodities Transiting the Panama Canal. Source: Panama Canal Authority.

Commodity	**2011**	**2012**	**2013**
Barley	98,000	87,000	121,000
Corn	14,174,000	11,420,000	7,486,000
Rice	1,013,000	764,000	639,000
Sorghum	3,973,000	4,229,000	3,923,000
Soybeans	17,219,000	16,289,000	14,044,000
Wheat	1,319,000	1,228,000	2,910,000

The Panama Canal is of importance to the agricultural sector in the U.S., notably when looking at soybeans. In 2011, traffic of agricultural goods from the Atlantic to the Pacific was roughly about 12 times greater than traffic flowing from the Pacific to the Atlantic (Panama

Canal Authority, 2013). These agricultural goods were grains that included corn, soybeans, wheat, etc., but of these, soybeans comprised about 50 percent of the total amount of grains shipped through the Panama Canal from the Atlantic to the Pacific, with just under 17.2 million long tons of soybeans in 2011 (Panama Canal Authority, 2013). These movements through the Panama Canal are logical considering the growing trend of China's soybean imports, which can be observed in Figure 2.1. However, referring to Table 2.1 agricultural goods are decreasing in regards to shipments through the Panama Canal. This is most likely due to the heavy competition for transiting the canal from container ships transporting industrial goods. A report's findings in regard to U.S. soybean exports found that in 2007 the Mississippi Gulf ports accounted for 52 percent of U.S. total soybean exports and that the Pacific Northwest ports was equal to 27 percent of said exports (Marathon & Denicoff, 2011). Those statistics for 2011 are now at 64 percent for the Gulf and 20 percent for the PNW (Taylor, 2013).



Source: USDA Foreign Agricultural Service

Figure 2.1. China Consumpiton and Imports. Source: Foreign Agricultural Service: USDA, 2012.

Panama Canal Expansion

According the the Panama Canal Authority, the construction of this Panama Canal Expansion project consists of the removal of roughly 29 million cubic meters of material to increase the depth and width of Gatun Lake's navigational channels as well as the Culebera Cut (Panama Canal Authority, October 2012). This will increase Gatun Lake's depth by 1.5 feet allowing an extra 165 million cubic meters of water for an increased resevoir capacity to help control the locks (Panama Canal Authority, October 2012). The new locks will also contain 16 rolling gates weighing about 2,000 tons that run from a recess adjacent and perpendicular to the lock chamber. The new gate configuration turns each recess in a dry dock which in turn allows for uninterrupted maintenance making the new locks of the canal more efficient. The system will result in increased handling capacity as well as flexibility by the offerings of shorter maintenance times at lower cost.

The capacity of the locks will increase vastly by becoming wider, longer, and deeper in order for much larger ships to transit the differing elevations of the canal. Larger locks have raised concerns in regards to the water supply in Panama, as a decent portion of Panama's fresh water supply comes from Gatun Lake. As Reagan (2009) notes, “the biggest tax on the water supply, though, is the canal itself. On average the canal requires more than 2 billion gallons of water per day to fill the locks for passing ships”. This statement was in regards to the Panama Canal before the expansion. In theory doubling the capacity would also double the water consumption, if engineers stuck with the locks traditional designs of hinged miter gates.

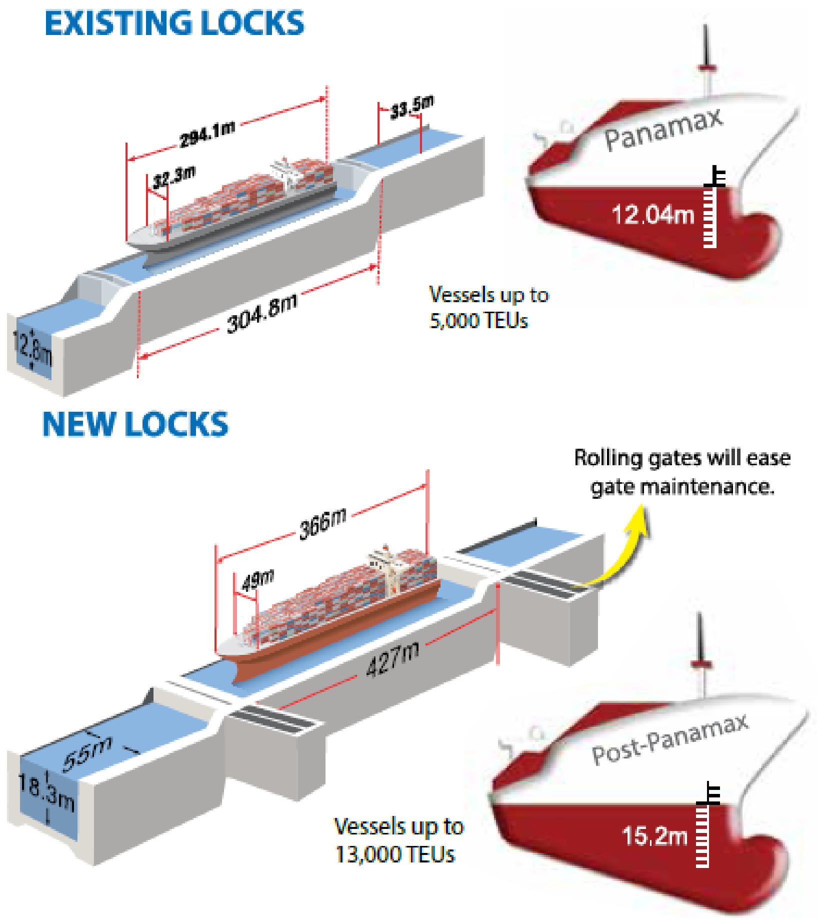


Figure 2.2. General Information on the New Locks. Source: Panama Canal Authority, 2012.

Water supply issues were then resolved by a visit to Hohenwarthe Locks on the Elbe River in Germany. Canal officials decided to implement a similar solution, by recycling the water being used in transit, that is otherwise flushed out to sea. These water consumption savings are to be done by implementing a water-saving basin system that the Panama Canal Authority estimates a reduction in the use of water by 7 percent than the existing locks and also recycling 60 percent of the water used for each transit through the canal. Reagan (2009) also notes that filling each chamber with 15 million cubic feet, which raises vessels 30 feet, is expected to only take around 10 minutes. A representation of the water-saving basins can be seen in Figure 2.2 below.

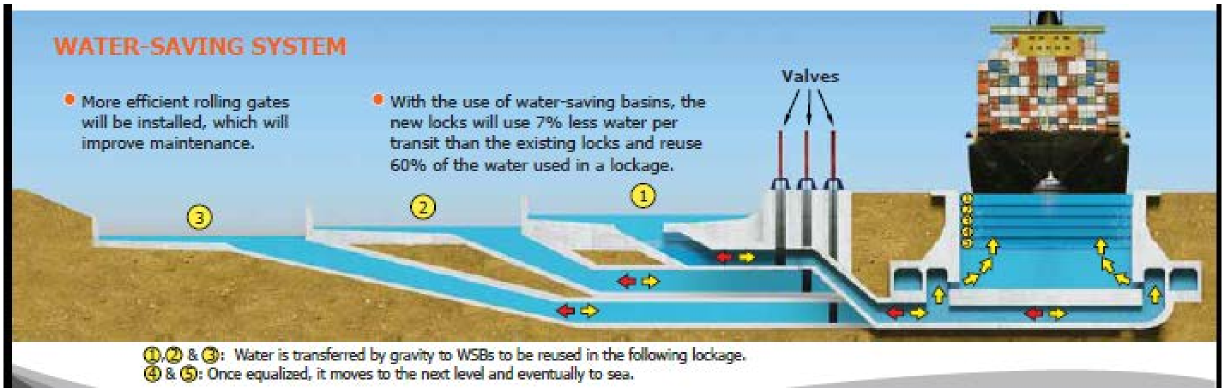


Figure 2.3. Water Saving System. Source: Panama Canal Authority, 2012.

Reagan (2009) notes that “The Panama Canal Authority esimates a 35 percent increase in cargo volume through 2025 – and additional toll revenues of $10 billion”(para. 24). Dengo (2012) noted that the Panama Canal “ranks among the most productive port systems in the Americas, handling 6.5 million TEUs in 2011 and with projections for 8.4 million TEUs by 2015” (p. 13). The same article found that the Panama Canal expansion is expected to be felt in varying market segments and that grain is the second most critical commodity to transit the canal that will benefit due to the expansion, which originates from the Midwest and is fed down to the gulf at an annual average of about 40 million metric tons of grain, particularly soybeans and corn (Dengo, 2012). The article notes that at the gulf ports the grains are loaded into dry bulkers that ship off to the Asian markets via the Panama Canal, but the expanded canal connecting 144 different shipping routes, allows for vessels of around 100,000 deadweight tonnage, generating economies of scale in ocean freight rates (Dengo, 2012).

Rabobank also published a report on their predictions of the estimated savings and impact that the Panama Canal expansion will bring. The author of this report estimates that after the Panama Canal is expanded U.S. grains that are being shipped to Asia should see an estimated 12 percent reduction in the cost of shipping (Sawyer, 2013). Sawyer (2013) is quoted as saying

"The Panama Canal expansion is great news for American competitiveness" in regards to Brazil and Argentina. Rabobank also offers that "ocean freight accounts for 60 percent of total shipping cost, so increased shipping capacity has a material effect on cost savings" (Sawyer, 2013).

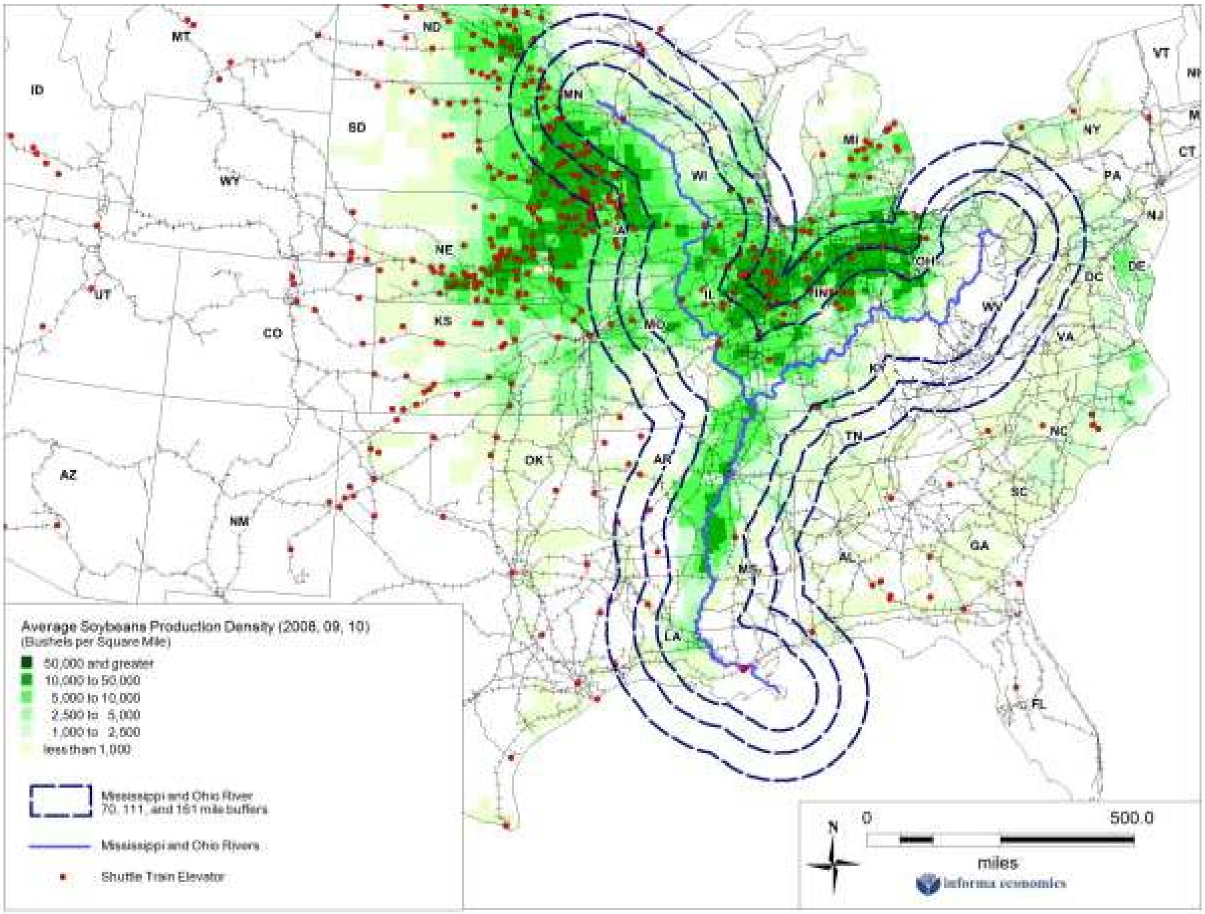


Figure 2.4. Mississippi and Ohio River Soybean Draw Areas. Source: Informa Economics, 2011.

Figure 2.4. was taken from a report by Informa Economics that was prepared for United Soybean Board, U.S. Soybean Export Council, and Soy Transportation Coalition. It was meant to show the different areas of U.S. soybean production that would be caputured by the Gulf because of the Panama Canal expansion. The inner ring shows what production areas are being sent to the Gulf now under current Panama Canal conditions. The two outer lines represent the range of production that could be captured after the Panama Canal expansion is complete. As seen it

would appear that Northwestern Iowa, Eastern South Dakota and Western Minnesota would start to ship soybeans to the Gulf. This map was procurred to also show where the majority of U.S. soybean production is coming from, as well as shuttle train elevator locations.

CHAPTER 3. REVIEW OF LITERATURE

This chapter presents previous studies regarding the transportation of agricultural commodities using spatial models, including spatial optimization models using linear programming and spatial equilibrium models using quadtratic programming. Spatial optimization models usually define their objective as minimizing costs, while spatial equilibrium models define the objective as maximizing net social payoff or also known as the summation of producer surplus, consumer surplus, and potentially government revenue given tariffs or quotas. These models are reviewed in terms of their methodology along with their notable findings.

Spatial Optimization

Fedeler and Heady (1976) used a spatial optimization model to determine how grain marketing and transportation are interdependent for agricultural commodities. A linear programming model was formulated using ten different model options to compare the changes in the results. Some of these included increasing exports by 25 percent or increasing rail costs by 10 percent etc. Fedeler and Heady's findings were that alternative transportation modes and grain flows are sensitive to transportation cost changes and the distribution of exports among ports. However, Fedeler and Heady found that location of grain production is not sensitive to these changes.

Barnett, Binkley, and McCarl (1985) performed a study on port capacity constraints and grain shipments. Barnett et al. study is like many others in this section using linear programming to minimize costs, but it is unique in that it set up as a network flow model that allows for storage activities at locations such as local grain elevators. Barnett et al. (1985) study is also different by having three different time periods in which the model is finding the least-cost pattern of delivered prices. Also, the author's separate the optimization model into quarters as grain shipements and flows can be very seasonal as well as how grains are shipped for example the frozen Mississippi in winter months cannot be used. Barnett et al. concluded as did Fedeler and Heady that transport rates are more influential than changing a particular locations export demand.

Wilson, Koo, Taylor, and Dahl (2005) analyzed the longer-term competitiveness of agricultural production and trade of 6 grains by developing a spatial optimization model based on long-run competitive equilibrium of world grain trade. Although 6 crops were used in the study, the paper focused on corn and soybeans as the authors determined these two crops would be the most dynamic or most likely to change due to changes in demand. Limiting the scope of the study to corn was due to the changes in the ethanol industry over the last couple decades. Soybeans was another focus not only because of the changes in Brazil's soybean production, but also because of China's exponential jump in soybean consumption and imports. In a figure within this study it shows China's production, consumption and imports of soybeans. This figure shows a fairly constant production, but not until 1996 do Chinese imports and consumption increase rapidly. This is most likely due to the reduciton of trade barrier as China shifted from a communist type of economy to more of a free market. So, Chinese soybean imports went from about zero in 1995 to 20 million metric tons in 2004.

Wilson, Koo, Taylor, and Dahl (2005) used a spatial optimization model containing 20 importing and exporting countries along 6 different crops with the U.S. being split into 15 producing and consuming regions. The objective of the model was to minimize productions costs in producing regions as well as transportation costs from producing regions to import regions. The objective function of the model is specified as follows:

$$W = \Sigma_c \Sigma_i PC_{ci}A_{ci} + \Sigma_c\Sigma_i\Sigma_j t_{cij}Q_{cij} + \Sigma_c\Sigma_i\Sigma_p t_{cip}Q_{cip} + \Sigma_c\Sigma_p\Sigma_q t_{cpq}Q_{cpq} + \Sigma_c\Sigma_p\Sigma_q (t_{cpq} + \alpha)Q^P_{cpq} + \sum_c \sum_q \sum_j t_{cqj}Q_{cqj}$$

where W is the objective function to minimize all costs, c defines each of the 6 different crops, i is the index for producing regions in exporting countries, j is the index for consuming regions in both exporting and importing countries, p is the index for ports in exporting countries, q is the index for ports in importing countries, PC_{ci} is the production cost of crop c in producing region i, A_{ci} is the area used to produce crop c in producing region I, t is the transportation cost per ton, Q is the quantity of non-Panama Canal crops shipped, Q^P is the quantity of crops shipped through the Panama Canal, and lastly α is the tariff used in the Panama Canal or otherwise thought of as the toll rate. This objective function is subject to a set of linear constraints:

1) $Y_{ci}A_{ci} \geq \Sigma_jQ_{cij} + \Sigma_pQ_{cip}$
2) $\Sigma_cA_{ci} \leq TA_i$
3) $A_{ci} \geq MA_{ci}$
4) $\sum_iQ_{cij} + \sum_qQ_{cqj} \geq MD_{cj}$
5) $\Sigma_c\Sigma_iQ_{cip} \leq PC_p$
6) $\Sigma_c\Sigma_p\Sigma_qQ^P{}_{cpq} \leq PCC$
7) $\Sigma_iQ_{cip} = \Sigma_jQ_{cpq}$
8) $\sum_pQ_{cpq} = \sum_jQ_{cqj}$

where Y is the yield/hectare in producing regions in exporting countries, TA is the total arable land in each producing regions in exporting countries, MA is the minimum land used for each crop in producing regions in exporting countries, DD is the domestic demand in consuming regions in exporting countries, MD is the import demand in importing countries, PC is the handling capacity in each port in both exporting and importing countries, and PCC is the throughput capacity for grains at Panama Canal. The interesting thing in regards to this model is that the authors used a double log functional form in their regression equations and an independent trend variable to forecast yields and consumption of the grains to forecast to 2025, whereas most linear programming models contain a set production level and set consumption level.

The findings from the above study by Wilson et al. (2005) were that the world import demands for all grains are expected to increase by about 47 percent for the 2001-2025 period. China's import demand for all grains and oilseeds is expecting about a 217 percent increase. The study also finds substantial growth in Brazilian soybean exports as well as an expected increase of 23 million metric tons of exports from Argentina in soybeans and wheat. While U.S. exports from the gulf were estimated to grow by 26 million metric tons as compared to marginal level of growth in agricultural exports from the PNW port in the U.S.

Wilson, Koo, Taylor, and Dahl (2007) performed a very comparable study to their 2005 study on the *Fundamental Factors Affecting World Grain Trade in the Next Two Decades,* and published the manuscript to Transportation Research Part E: Logistics and Transportation Review, except this time there was an emphasis on the effects of the Panama Canal Expansion. Wilson et al. (2007) used the same model as from their previous study. Only one change was the Panama Canal capacity constraint in order to see the effects of an expansion as a before and after snapshot. Wilson et al. (2007) concluded that 62 million metric tons would increase to 80 million metric tons (mmt) in 2025 if no expansion were to take place, but with the expansion the study offered that flows through the canal would increase by 3 mmt in the near term and would increase by 4 mmt by 2025. The total grain flows transiting the canal after expansion would increase from 65 mmt to 85 mmt in 2025.

Another study from Wilson, Dahl, Taylor, and Koo (2007) analyzed delay costs and the competitive position of grain shipments on the Mississippi River. The model was formulated by way of a spatial optimization model of world grain trade. Like previous studies the objective function of their model is to minimize production and shipping costs. Unlike the other studies the authors include various other costs incurred with the production and transportation of agricultural commodities, such as; production subsidies in the exporting country, import tariffs in the importing country, and delay costs associated with barge shipments along the Mississippi river. As for their linear constraints the authors added one new constraint for a total of nine which was to constrain the capacity of commodities at river access points such as; Minneapolis, Louisville, and St. Louis. Delay costs were derived using simulation procedures.

Wilson et al. (2007) with regards to grain shipments along the Mississippi river system from found that river shipments went from 51 mmt in the study's base case model of sihpments in the time frame of 2001 to 2004, but then increased to 65 mmt in 2020. Although, grain shipments decreased to 60 mmt in 2030 and the authors noted that, "The reason for the decrease was that while soybean export continued to increasee, corn shipments decreased by 6 mmt between 2020 and 2030 and wheat shipment decreased by over 3 mmt" (Wilson, Dahl, Taylor, & Koo, 2007). The study found that lower delay costs due to larger lock capacities increased Mississippi river shipments of soybeans between 2 mmt and 3 mmt. Wilson et al. (2007)

concluded inter-reach competition was increased along the Mississippi river due to the capacity increases in the reaches further up the river, because as the decreased delay costs associtated with the expanding capacity of the upper river locks that shipping amounts decreased along the lower reaches. The study also concluded that grain shipments down the Mississippi would shrink by about 7 mmt per year as a 50 percent increase in non-grain traffic was allowed to use the river system. Lastly, Wilson et al. (2007) found that as the railroad capacity constraint was relaxed Mississippi barge shipments would decrease. Originally the railroad constraint was limited to 131 mmt, then released to 161 mmt, and finally increased to 201 mmt. The corresponding barge shipment quantities decreased as the model allowed for more railway grain shipment. The base model started with barge shipment of 51 mmt then fell to 48 mmt and then shrunk to 36 mmt coming down the river. As seen the jump from 161 mmt to 201 mmt allowed to be shipped by rail had a profound affect on shipments down the Mississippi, as it fell by 12 mmt versus the 3 mmt decrease for the first change in railway capacity.

Fan, Wilson, and Tolliver (2009) studied the logisitical rivalries and port competition container flows going to US markets. An optimization model was used to determine the impacts of certain changes to Canada’s logistic systems as well as the expansion of the Panama Canal, by minimizing costs. The objective of the study was to assess inter-port rivalry and changes in container flows as a reaction to changes in the competitive environment. The interesting inclusion to this model was a congestion function at container ports to quantify traffic diversions to Canada (mainly Prince Rupert) and through the Panama Canal due to the overcrowding of the US west coast ports as well as the associated costs. The authors then explicate the impacts of stochastic demand on container flows. The congestion function as defined by Fan et al. (2009) offer that “it represents port congestion costs of inbound containers. The different cost structures correspond to various annual arrival rates of containers. When the arrival rate approaches the TEU handling capacity , the average waiting time in queue increases to infinity and the import TEU will incur very high costs that could result in diverting containers to other ports" (p. 331).

Fan, Wilson, and Tolliver (2009) findings were that all TEU flows to the west coast ports such as; Los Angeles, Oakland, Portland, and Seattle all decreased their handling of TEUs with the Panama Canal expansion and allowing flows to Prince Rupert, Canada. The results of the study are shown in Table 3.1 and differing from the west coast ports, Houston's percent increase was 22 percent and had the second lowest waiting time.

Table 3.1. Estimated Container Flows to the West Coast. Source: (Fan, Wilson, & Tolliver, 2009).

Port	Estimate w/o Prince Rupert and no expansion of Panama Canal	Estimate w/Prince Rupert and expansion of Panama Canal	Percentage Change	Expected waiting time (days)
Los Angeles	3,773,160	3,666,550	-3%	2.2
Long Beach	3,000,000	3,000,000	0%	2
Oakland	594,335	529,275	-11%	0.7
Portland	46,911	39,071	-17%	0
Seattle/Tacoma	1,305,603	1,292,182	-1%	0.6
Houston	550,000	673,114	22%	0.38
Prince Rupert	0	117,705	-	-

Fan et al. (2009) concluded that Prince Rupert will grow its market share and become largely resiliant to market volatility, but also expects Houston to compete with Prince Rupert dependent upon the longer shipping times to Houston when compared to those being diverted to Prince Rupert.

DeVuyst, Wilson, and Dahl (2009) incorporated quantifiable risks associated with projecting commodity flows within the framework of a spatial optimization model. The model forecasted that US exports will decrease after 2010, and that barge traffic will rise after 2020. As in some of the previous the decline in US exports is linked to the increasing domestic uses within the US such as corn use for the ethanol industry. Devuyst et al. (2009) also found that delay costs have a large impact on shifting shipping movements to rail from the Mississippi river system due to congested barge traffic. The authors also conclude that simultaneous expansion of the river locks for greater capacity results in only a modest increase in barge shipments.

Ligmann-Zielinska, Church, and Jankowski (2008) examined the usefulness of spatial optimization as a modelling technique for sustainable land-use allocation. The author's developed a new spatial multiobjective optimization model that supports trade-off evaluation of the optimization of spatial objectives versus those that are generating divergent solutions. Ligmann-Zielinska et al. (2008) found that the relaxtion of spatial objectives is necessary for procuring more diversified patterns.

Spatial Equilibrium

Samuelson's (1952) 'net social pay-off' in spatial equilibrium models is also observed in the Takayama and Judge (1964) and is represented by equation (7).

$$
\begin{aligned}
\mathrm{NSP} = {} & \sum_{i} \int_{0}^{\Sigma_j x_{ij}} \Big(\lambda_i - \omega_i \sum_{j} x_{ij}\Big) d\Big(\sum_{j} x_{ij}\Big) \\
& - \sum_{j} \int_{0}^{\Sigma_i x_{ij}} \Big(\mu_j + \eta_j \sum_{i} x_{ij}\Big) d\Big(\sum_{i} x_{ij}\Big) - \sum_{i} a_i - \sum_{i} \sum_{j} t_{ij} x_{ij}
\end{aligned}
\tag{7}
$$

Takayama and Judge (1964) indicate how spatial equilibrium models may be handled as quadratic programming prolems. Takayama and Judege also illustrate the workings of a mathimatical model similar to equation (7) by way of Figure 3.1. In Figure 3.1 net social payoff is the area $\Delta\widehat{p_2}c\overline{p_2}$ plus $\Delta\overline{p_1}f\widehat{p_1}$. However, Araujo-Enciso (2011) contributed a study that takes the Takayama and Judge framework for spatial equilibrium but revised the econometric techniques using vector error correction models to see how the theory would hold up. Araujo-Enciso was able to introduce dynamics and disequilibrium into the model to generate artificial data or in other words prices.

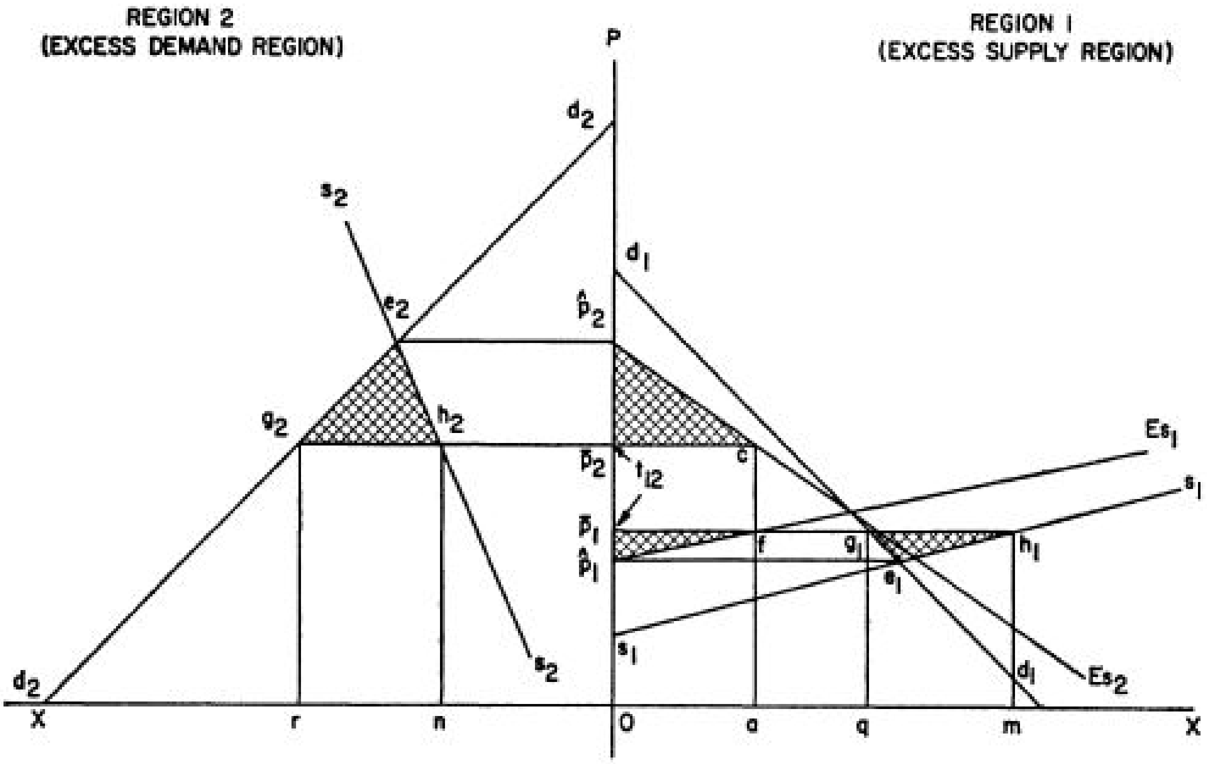


Figure 1. Spatial equilibrium prices and flows

Figure 3.1. Spatial Equilibrium Diagram. Source: (Takayama & Judge, 1964).

Takayama and Judge depict a spatial equilibrium model graphically in Figure 3.1. Samuelson (1952) offers a graphical representation of where the net social payoff will be maximized in Figure 3.2. Samuelson provides the social pay-off function as it is seen in many microeconomic textbooks showing a non-linear utility curve. However, Samuelson incorporates the transport cost into the diagram as is depicted in the mathematical model of social pay-off minus transportation costs is equal to ones net social pay-off, which is maximized at the point where the distance between the two curves is the greatest.

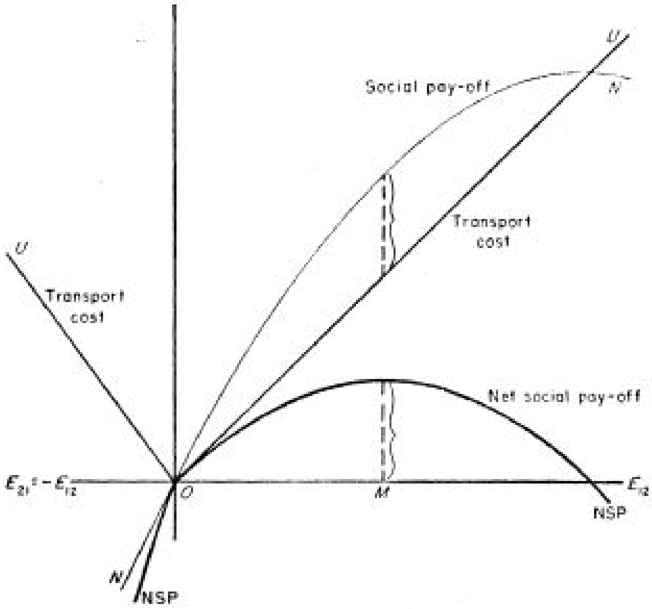


Figure 3.2. Maximized Net Social Pay-off. Source: (Samuelson, 1952).

Moon and Koo (2006) conducted a study for which the objective was to evaluate the impacts of alternative Panama Canal toll rates in the shipping of soybeans from major exporting countries to major importing countries. A single commodity spatial equilibrium model was developed that had a base case model and other alternative scenarios regarding the Panama Canal toll rates. These alternative scenarios were run and then compared to the base case scenario in order to accomplish the objectives of comparing US competitiveness in exporting soybeans. Moon and Koo (2006) developed a spatial equilibrium model with a defined objection function of maximizing ‘net social payoff’ as defined by Samuelson (1952), in equation (2):

$$\begin{aligned} W = & \sum_{n} \int M_n(Q_n) dQ_n - \sum_{p} \int E_p(Q_p) dQ_p - \sum_{p} \sum_{n} (tc^1{}_{pn} + ha_p + ta_n - es_p) Q^1{}_{pn} \\ & - \sum_{p} \sum_{n} (tc^2{}_{pn} + ha_p + \alpha + ta_n - es_p) Q^2{}_{pn} - \sum_{i} A_i PC_i - \sum_{i} \sum_{j} tc_{ij} Q_{ij} \\ & - \sum_{i} \sum_{p} tc^t{}_{ip} Q^t{}_{ip} - \sum_{i} \sum_{p} tc^r{}_{ip} Q^r{}_{ip} - \sum_{i} \sum_{a} tc^t{}_{ia} Q^t{}_{ia} - \sum_{i} \sum_{a} tc^r{}_{ia} Q^r{}_{ia} \\ & - \sum_{a} \sum_{p} tc^b{}_{ap} Q^b{}_{ap} \end{aligned} \quad , \qquad (2)$$

This mathematical model is somewhat comparable to the model presented under the spatial optimizaiton section above, but instead of minimizing all costs as in a spatial optimization model the authors subtract the sum of costs from the maximized net social payoff value, which equates to being the first four terms from equation 2. Another differentiating feature between spatial optimization and spatial equilibrium are the integrals seen in the first two terms of eqution 2. In order to find the social payoff value an integral must be used to find the area of producer and consumer surplus. This is because supply and demand curves are seldom linear and to calculate the area underneath those curves integrals are needed, just as a derivative is used to calculate the instantaneous rate of change of a function and an antiderivative is in fact a integral. That is also why quadratic programming is needed, in case of non-linear supply and demand curves. Transportation rates were then found econometrically.

Moon and Koo (2006) found that the total quantity of all soybeans traded through the canal accounted for 21 percent of the the world soybean market. Also, findings indicated that 25 percent of the total soybean imports for China came through the canal. Moon and Koo (2006) also discovered that the southern Brazil port and Argentina port increased their export quantities as toll rates at the Panama Canal rose. Although, those same two ports also had the largest increase in their export price as the toll rate rose, but this is due to the fact that those ports had a cost advantage in shipping soybeans to East Asia because their export price was so low already. As seen below in Table 3.2 Brazil south and Argentina export ports increased in export price by 3 dollars stayed relatively the same or even dropped as toll rate went up because that ports quantity through the canal decreased altogether because of the high toll rates. Moon and Koo (2006) concluded that the US gulf ports were the most sensitive to changes in the Panama Canal toll rates.

Table 3.2. Export Price and MMT Handled by Export Port. Source: (Moon & Koo, 2006).

Country	US				Brazil		Argentina
Port	Gulf	PNW	Atlantic	Lake	North	South	
Price ($)							
Zero	228.57	228.56	235.74	226.78	194.81	205.12	180.64
$5	226.63	232.26	232.12	224.04	192.94	208.24	183.75
$10	226.33	231.99	232.89	224.82	192.85	208.2	183.71
Quantity (1000 MT)							
Zero	19,750	3,581	377	1,147	9,807	9,914	7,247
$5	19,587	3,637	371	1,134	9,787	9,946	7,272
$10	19,563	3,633	373	1,138	9,786	9,946	7,272

For a more recent study the objective function of the spatial equilibrium model was to maximize producer and consumer surplus minus cotton handling, storage, and transportation costs (Costa & Rosson, 2012). The study's goals were to see how the PCE will impact U.S. cotton exports as well as its effects on the global cotton industry. Costa and Rosson (2012) evaluated their spatial equilibrium model using quadratic programming by running three different scenarios. The first was a 10 percent reduction in ocean freight rates from vessels coming from gulf and south atlantic ports, the second was another reduction in ocean shipping rates to 28 percent in costs for the same ports, and the third scenerio incorporated those percent reducitons in shipping costs to both US gulf and south atlantic ports as well as west coast ports to see the competitivness among US ports to attract more vessels.

Costa and Rosson (2012) found that the 10 percent decrease in ocean freight rate increased the amount of cotton transiting through the Panama Canal from 5,041.8 thousand bales to 7,590.6 thousand bales after the Panama Canal Expansion. Exports from the gulf and atlantic ports of the US increase as associated shipping costs decreased due to projected economies scale for much larger vessels to transit the canal now. In the scenario of a 10 percent reduciton in shipping costs there was a 50.5 percent increase of cotton exports coming from the east side ports of the US. In the other scenerio of a 28 percent reduction in shipping cost there is a 90.3 percent increase in US cotton exports from the east coast.

Fuller, Fellin, and Eriksen (2000) conducted a study to determine the influence of increasing Panama Canal tolls or even a canal closure would have on the US grain exports and producer revenues. The grains included in this study were corn and soybeans, and the effects upon these commodities were modeled once again by a quadratic programming model. To ultimately generate interregional trade flows and prices that result in maximizing the surpluses of consumers and producers minus the associated grain marketing costs.

Fuller et al. (2000) found that from the then current toll rate at the Panama Canal of \$1.50/ton to \$2.50/ton did not effect US commodity flows in a great way, but when the toll increased by \$2.00/ton and up to \$3.50/ton and beyond there were significant changes in flows and exports of US corn and soybeans. The percent increase of exports shipping out of the Pacific Northwest ports increased from 25 percent to 40 percent for corn and from 24 percent to over a 100 percent in soybean exports out of the PNW, given a 2 dollar increase in the toll rate making it \$3.50/ton. Fuller et al. (2000) discovered that closing the Panama Canal would result in corn and soybean exports decling from US Gulf ports by 7.8 mmt, while exports in the Pacific

Northwest ports would increase by 6.7 mmt and shipment around the African Cape would increase to 12.5 mmt. Other interesting findings in the article were that U.S. corn and soybean exports to Europe would increase by 5.43 mmt and a decrease in exports to Asia and other regions that were originally accessed by the canal would decrease by 2.23 mmt. Lastly, Fuller et al. (2000) uncovered that the Panama Canal closure would reduce U.S. corn and soybean producer revenues by $303 million, annually.

Qualitative Empirical Studies

There are a number of empirical studies that are qualitative in nature due to experience and knowledge in that particular area of research or industry. Some of these studies are reviewed in chapter 2 that include; (Dengo, 2012), (Rodrigue, 2010), and (Sawyer, 2013). The authors of these studies all believe that the Panama Canal Expansion will decrease shipping costs. Sawyer (2013) of Rabobank states that there will be a decrease in the shipping cost of grains that is around 12 percent reduction. Rodigue (2010) wrote a report in regards to the effect of the PCE on container shipping. Lastly, Dengo (2012) of the Panama Canal Authority discusses the increases in grain and coal shipments through the canal once the PCE is completed.

Salin (2010) from the Agricultural Marketing Service wrote a report on the *Impact of Panama Canal Expansion on the U.S. Intermodal System*. The study explores the transit statistics at the Panama Canal as well as its competitiveness with the Suez Canal. Salin also discusses the competitiveness of the U.S.’s intermodal system for shipping to the East Coast from Asia versus that of the Panama Canal. Salin’s conclusions are that U.S. will need to invest in further infrastructure improvements if the U.S. intermodal system is to stay competitive.

CHAPTER 4. DEVELOPMENT OF EMPIRICAL MODEL

Chapter 4 discusses the methodology used in this study to estimate the flows and costs of transporting soybeans. Some transportation costs are estimated using econometric tools. A spatial optimization model based on a linear programming algorithm is used to determine the optimal flows of soybeans from producing regions in the U.S. to domestic consuming regions and from export ports to ports in importing countries.

Methodology

As stated in chapter 3 there are many studies that deal with grain transportation. These studies are predominantly separated into two categories depending on the type of analysis, spatial optimization and spatial equilibrium models. Spatial optimization models are based on linear programming algorithms, in which the objective function is to minimize. The production costs of commodities in the producing countries, as well as the transportation and handling costs for shipping the commodities from production regions to the domestic consuming regions within that export country, and also the associated shipping costs from exporting countries to the importing countries. On the other hand, the spatial equilibrium model is based on a quadratic programming algorithm in which trade flows and prices are optimized by maximizing net social payoff as defined by Samuelson (1952). Spatial equilibrium models optimize international trade flow of grains from exporting countries to importing countries under the estimated export supply and import demand for grains, as well as the transportation infrastructure.

In order to model the effect of the PCE upon the distribution and transportation costs associated to U.S. soybean production, consumption, and exports, as well as Brazil and Argentina soybean exports, a spatial optimization model was developed. Like previous studies, this study minimizes all transportation costs from U.S. producing regions to domestic consuming regions and then from export ports to ports in importing countries. Therefore, the structure of this model is similar to those in the previous studies. However, this study differs from the previous studies in the following areas; (1) this study uses updated data related to (Moon & Koo, 2006), (Wilson, Koo, Taylor, & Dahl, Fundamental Factors Affecting World Grain Trade in the Next Two Decades, 2005), and (DeVuyst, Wilson, & Dahl, 2009), (2) it includes more production regions within the U.S. than previous studies (Tangen, Koo, & Taylor, 2011), to give a better idea of the domestic flows of U.S. soybeans, and (3) this spatial optimization model is used to optimize the business model of the Panama Canal Authority in determining the toll rate. This study determines or predicts a Panama Canal toll rate, which maximizes toll revenue after expansion for 2015. Many studies look at how the PCE will affect global grain trade as well as the quantities of grain shipped through the canal. Other studies evaluate what changing the Panama Canal toll rates will do to the domestic flows, quantities shipped through the Panama Canal, or what commodities will be flowing out of which export ports.

To evaluate the impact of the Panama Canal expansion upon Argentina, Brazil, and U.S. soybean exports, the U.S. was divided into 48 producing regions and 11 domestic consuming regions. There are 7 U.S. export ports, 2 Brazil export ports, and 1 export port in Argentina, that ship to 13 different importing regions. Production regions were determined by grouping agricultural districts by comparable yields that were also in close proximity to one another. The 11 domestic consuming regions consist of soybean crushing facilities located throughout the U.S. as soybean crush comprises over 90 percent of domestic consumption. Lastly, the 13 foreign importing regions are countries and the sum of close proximity countries that are major importers of soybeans. The modes of transportation used for this study are trucking, rail, barge, and ocean vessels. Trucking, rail, and barge comprise domestic movements while ocean vessels account for cross-country shipments.

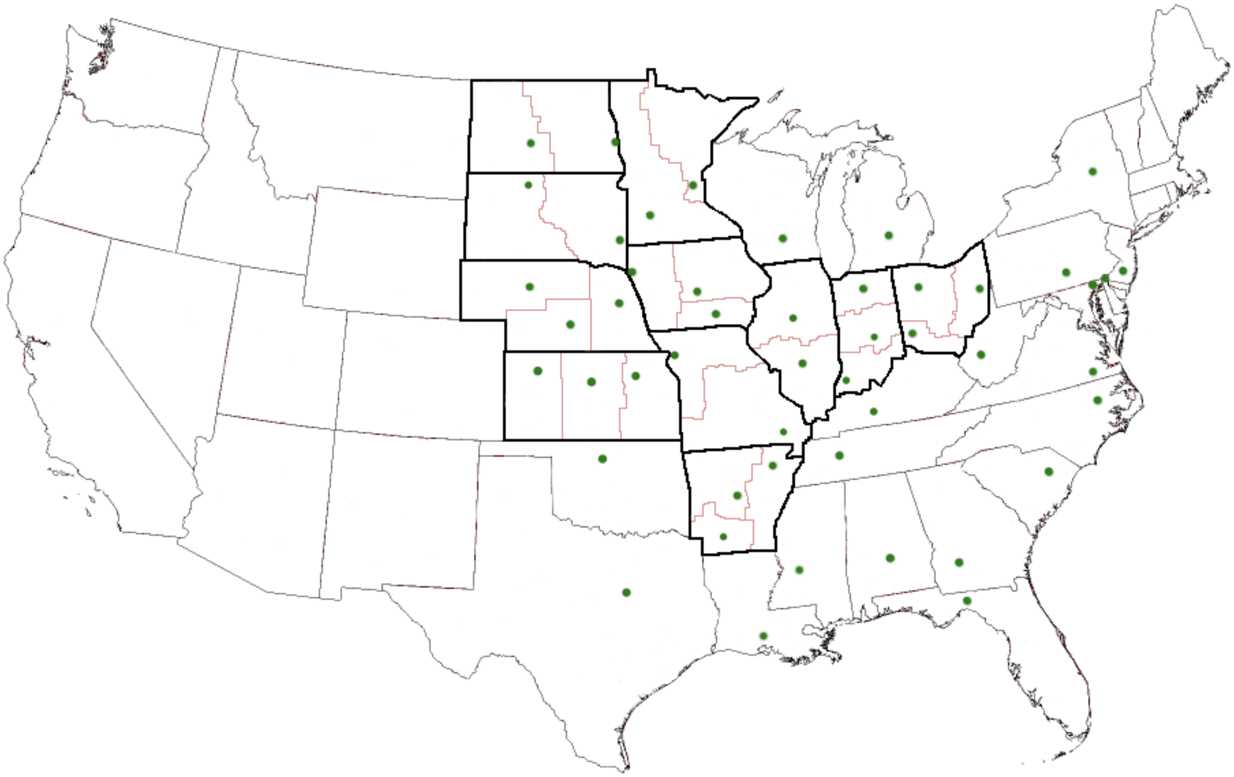


Figure 4.1 U.S. Production Regions.

Figure 4.1. is a map of this study's chosen prodcution regions by state, as well as split up and grouped by agricultural district for major producing states that include; North Dakota, South Dakota, Minnesota, Iowa, Nebraska, Kansas, Missouri, Arkansas, Illinios, Indiana, and Ohio.

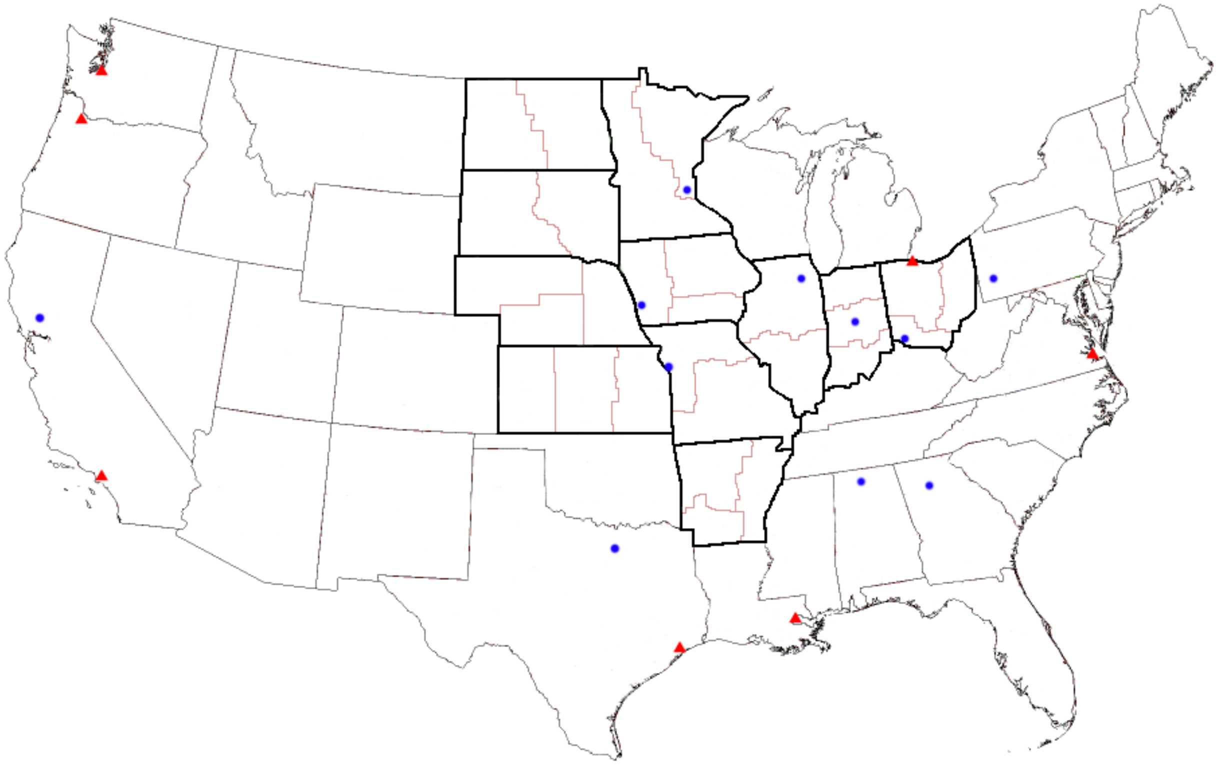


Figure 4.2 U.S. Domestic Consumption and Export Ports.

Figure 4.2. is a map of the locations of U.S. soybean crushing facilities and export ports that were used as domestic consumption points and U.S. export points. There are 11 domestic consuming points that are represented by dots. There are 7 export ports chosen for this study that are signified by triangles.

Mathematical Model

A model developed for this study is a spatial optimization model based on a linear programming algorithm. The objective function of the model is to minimize all transportation costs from producing regions to domstic consuming regions as well as the shipping costs associated in shipping soybeans from producing regions to export ports and then to ports of the importing countries. The objective function is optimized subject to a set of linear equations. The objective function is specified as:

(1) Minimize Z =

$$\Sigma_i \Sigma_c \Sigma_m t_{icm} Q_{icm} + \Sigma_i \Sigma_p \Sigma_m t_{ipm} Q_{ipm} + \Sigma_p \Sigma_j \Sigma_m t_{pjm} Q_{pjm} + \Sigma_p \Sigma_j \Sigma_m \left(t_{pj} + \alpha + \sigma\right) Q_{pj}^{P}$$

Where:

m = index for mode of transportation; 1 for truck, 2 for rail, and 3 for barge

i = index for producing regions in the U.S.

c = index for consuming regions in the U.S.

p = index for ports in exporting countries

j = index for ports in importing countries

t = transportation cost per ton

Q= quantity of soybeans shipped

α = toll rate per ton used at the Panama Canal

σ = the cost associated with delays

The first two terms of equation 1 (objective function) represents the transportation costs of shipping soybeans from producing region i to domestic consuming region c, and to ports p for export in the U.S. by different modes of transportation. The third term represents ocean freight from ports in Argentina, Brazil, and the U.S. to ports in the importing regions j. The last term is similar to that of the third; however, it includes the cost of the required tolls α for utilizing the

Panama Canal, as well as the vessels operational costs for waiting to transit the canal due to congestion (σ).

The objective function is subject to a set of linear constraints as follows:

(2) $\Sigma_i\Sigma_m Q_{ic} \geq DD_c$

(3) $\Sigma_p Q_{pj} \geq MD_j$

(4) $\Sigma_i\Sigma_m Q_{ip} \leq PC_p$

(5) $\Sigma_p\Sigma_j Q^P{}_{pj} \leq PCC$

(6) $\Sigma_i Q_{ip} = \Sigma_j Q_{pj}$

Where:

DD = domestic demand in consuming regions in the U.S.

MD = import demand in foreign importing countries

PC = port handling capacity for export ports

PCC = throughput capacity for soybeans at the Panama Canal

Equation 2 indicates that domestic shipments to consuming regions have to be larger than or equal to U.S. soybean consumption in consuming regions. Equation 3 states that foreign import demand must be less than or equal to soybeans shipped from producing regions to export ports. Equation 4 represents that soybean exports cannot exceed or has to be less than or equal to a ports annual handling capacity. Equation 5 is the handling capacity of the Panama Canal and that soybeans shipped through the Panama Canal have to be less than or equal to that capacity. Lastly, equation 6 is an inventory-clearing constraint at export ports, meaning that export ports cannot carry any inventory.

Data

The data used for this model can be broken down into four different groups: production of soybeans (yields and acres harvested) in producing regions, domestic transportation costs (including truck, rail, and barge), ocean freight rates, and the sum of consumption, which includes domestic consumption and forein imports (import demand for soybeans from the U.S., Brazil, and Argentina).

Production data for producing regions of soybeans in the U.S. was gathered from the *Crops* online database (National Agricultural Statistics Service, 2013) and included yields and acres harvested from the year 2009 through 2011. A 3 year average was used for yields and for harvested acres to potentially offset any major issues in production from year to year. As an example, if only one year of production data was used and that year was a drought the mathetical model could yield very inaccurate or different results. The years 2009 to 2011 were used because those were better than average production years, particularly 2009 and 2010. This is to help represent U.S. soybean trade under normal conditions. The production regions were grouped by agricultural districts as defined by the *National Agricultural Statistics Service* by proximity and comparable yields in bushels per acre. The 3 year average of those yields were then multiplied by the 3 year average of harvested acres to determine the production of soybeans in their associated production regions in bushels, which were then converted to tons. The average yields and harvested acres in each producing region are shown in Table 4.1. Southwestern Minnesota is the largest soybean producing region, followed by Northern Illinios. The average soybean production in the U.S. for 2009 – 2011 is 3.26 billion bushels.

Table 4.1. Production Regions and Their Associated Harvested Acres, Yield, and Production (2009-2011).

Production Region	3 Year Avg. Harvested Acres	3 Year Avg. Yield	3 Year Avg. Production in Bu.
AL	356,666.67	33.00	11,770,000.00
AR1	98,816.67	26.54	2,622,594.33
AR2	3,088,500.00	38.11	117,706,166.67
AR3	45,933.33	21.38	981,825.00
DE	174,666.67	37.83	6,608,222.22
FL	24,333.33	31.67	770,555.56
GA	276,666.67	28.00	7,746,666.67
IL1	4,753,666.67	52.09	247,602,651.11
IL2	4,349,666.67	43.38	188,703,038.89
IN1	1,884,666.67	47.48	89,479,785.19
IN2	2,345,333.33	49.70	116,563,066.67
IN3	1,123,333.33	41.81	46,967,814.81
IA1	3,957,666.67	51.24	202,808,429.63
IA2	4,259,333.33	52.26	222,585,661.11
IA3	1,279,666.67	47.05	60,208,316.67
KS1	187,000.00	41.70	7,797,900.00
KS2	1,611,000.00	34.83	56,116,500.00
KS3	2,099,000.00	32.87	68,987,133.33
KY	1,430,000.00	40.33	57,676,666.67
LA	980,000.00	38.67	37,893,333.33
MD	468,333.33	38.33	17,952,777.78
MI	1,990,000.00	42.50	84,575,000.00
MN1	6,995,333.33	42.25	295,552,833.33
MN2	161,333.33	32.08	5,176,111.11
MS	1,936,666.67	38.50	74,561,666.67
MO1	3,037,666.67	40.26	122,291,397.22
MO2	2,155,666.67	37.26	80,320,140.00
NE1	152,366.67	44.93	6,846,342.22
NE2	3,750,166.67	52.20	195,758,700.00
NE3	997,466.67	57.69	57,542,743.70
NJ	88,333.33	34.67	3,062,222.22
NY	270,000.00	44.67	12,060,000.00
NC	1,553,333.33	30.17	46,858,888.89
ND1	3,886,833.33	30.57	118,833,451.11
ND2	86,883.33	29.80	2,589,123.33
OH1	3,616,333.33	48.81	176,507,202.78
OH2	302,000.00	47.61	14,378,555.56
OH3	635,000.00	46.08	29,262,916.67
OK	376,666.67	23.00	8,663,333.33
PA	476,666.67	44.00	20,973,333.33
SC	460,000.00	24.33	11,193,333.33
SD1	4,054,666.67	38.77	157,212,942.22
SD2	79,733.33	29.53	2,354,126.67
TN	1,400,000.00	36.00	50,400,000.00
TX	155,000.00	24.67	3,823,333.33
VA	553,333.33	34.33	18,997,777.78
WV	18,666.67	38.00	709,333.33
WI	1,620,000.00	45.67	73,980,000.00

Domestic consumption of soybeans was determined by the U.S.'s soybean crush industry and its consuming regions were determined by soybean crushing plant locations. Soybean crushing statistics were collected from the *U.S. Department of Commerce* (U.S. Department of Commerce, 2011). The report gave crushing statistics for the major soybean crush states; Illinois, Indiana, Iowa, Minnesota, Missouri, Ohio, and then the last group of statistics was grouped as all other states. The grouping of all other states was then split evenly between 6 other soybean crushing locations for a total of 11 domestic consuming regions. A 3 year average of the soybean crush was then taken to determine the demand of domestic consuming regions.

The foreign import demand for soybeans was gathered from the *Production, Supply, and Distribution* online database (Foreign Agricultural Service, 2013). Import demand for foreign countries/regions was derived as a 3 year average of soybean imports for the years 2009 through 2011 and was converted from metric tons to short tons, shown in Table 4.2.

Table 4.2. Importing Regions and Their Associated Import Demand (2009-2011).

Importing Region	**3 Year Average of Import Demand in Tons**
China	59,490,935.83
Japan	3,335,222.62
South Korea	1,313,586.08
Taiwan	2,648,483.49
Southeast Asia	5,905,809.54
Mexico	3,904,749.46
Central America	284,028.54
Caribbean	167,183.68
South America	706,948.15
Nothern Europe	15,174,032.02
Southern Europe	1,552,787.35
Middle East	1,491,057.99
Nothern Africa	1,951,088.70

Cost data includes the domestic trasportation costs (using trucking, rail, and barge), and ocean freight rates. Domestic transportation costs for trucking was gathered from the *Grain Truck and Ocean Rate Advisory* (Agricultural Marketing Service, 2010). Trucking rates were extracted as the U.S. national average rate per ton-mile, which equated to $0.06 per ton-mile. Domestic transportation costs for rail and barge were collected as a cross-section data for 2010 from the *Grain Transportation Report* (Agricultural Marketing Service, 2010). Barge rates were derived as an average of 2010 $US/ton from river port origins to New Orleans. The data for barge rates are a vector as the Mississppi river only flows in one direction to New Orleans for export. Rail rates were estimated econometrically using monthly rail rates as a cross-section for the year 2010, and are reviewed in more depth later in this chapter. Ocean freight rates were also estimated using econometric methods from cross-sectional data for the year 2010 and that data came from the *Grain Market Report* (International Grains Council, 2011). Lastly, current Panama Canal toll rates were gathered from Panama Canal Authority (Panama Canal Authority, 2012).

Rail and Ocean Rate Estimation

The transportation costs for inland U.S. rail shipment were derived using OLS (Ordinary Least Squares) with a linear regression. The regression equation is represented by equation 1:

$$(1) \qquad RR = \alpha_0 + \alpha_1 Distance + \alpha_2 Shuttle^D + e$$

Where RR is the rail rate in dollars per ton from shipping origin to shipping destination as the dependent variable and was regressed against independent variables Distance and the dummy variable $Shuttle^D$. α_0 represents the intercept term and e is used to denote the error term.There were 376 observations in this cross section of data (Agricultural Marketing Service, 2010).

Distance is the rail distance from production regions to domestic consuming regions, as well as, distance from production regions to U.S. ports for export. The shuttle dummy variable represents rail rates between shuttle and unit trains; value of 1 for rail rates that are for shuttle trains versus those that have a value of 0 represent unit train shipments.

The estimated model is shown as follows:

$$\underset{(27.49)}{RR = 19.54} + \underset{(28.53)}{.0166 * Distance} - \underset{(-8.12)}{4.88 * Shuttle^{D}}$$

DF = 373

$R^2 = 0.69$

The numbers in paratheses represents the t-value of the corresponding variables. The variables both proved to be statistically significant with the correct coefficent signs. The coefficient for distance was about .02, meaning it costs 2 cents to transport a ton of soybeans 1 mile. The shuttle dummy coefficient is 4.88 meaning that if a shuttle train is used that the overall price will decrease by $4.88 per ton for the trip from point A to point B no matter the distance. The White Test was run to check for any heteroskedasticity issues, but none were found. The correlation coefficient between the independent variables equals 0.29 suggesting no sign of multicollinearity.

The transportation costs for ocean shipping from U.S. export ports to the foreign importing regions were estimated using the same method as the rail rate as seen above in equation 1 using OLS as the estimation procedure.

The estimated ocean shipping rate is defined in equation 2 below:

$$(2) \qquad OR = \alpha_0 + \alpha_1 Distance + \alpha_2 Vessel\text{-}Size^{D} + e$$

where OR is the ocean freight rate in dollars per ton in, shipping soybeans from export port to the importing countries port, as the dependent variable. The ocean freight rate was regressed against the independent variables of Distance and Vessel-Size^D. α_0 represents the intercept term and α_1 and α_2 are parameters of distance and vessel size values, respectively. e is the random error term. Equation 2 was estimated with cross-sectional data which were obtained from (International Grains Council, 2011) The estimated equation is shown as:

$$\underset{(6.38)}{OR = 14.83} + \underset{(10.97)}{.0043}*\text{Distance} - \underset{(-1.84)}{4.68}*\text{Vessel-Size}^D$$

DF = 29

$R^2 = .83$

Distance is measured in miles from export port to the foreign importing ports and vessel-size is represented by a dummy variable. The dummy variable is equal to 1 for vessels over 35,000 tons and 0 otherwise. The independent variables were both statistically significant, but distance was more so than the vessel-size dummy. The regression coefficient for the independent variable distance is .0043, meaning that it costs $4.30 to move a ton of soybeans 1,000 miles. A previous regression equation included the actual vessel size instead of grouping the vessel-size into two groups, but that independent variable turned out to be insignificant. The White Test to check for heteroskedasticity provided that the model specification showed no signs of heteroskedasticity. Multicollinearity was tested by obtaining the correlation coefficients and showed inconclusive signs of multicollinearity.

Base Case and Alternate Scenarios

The base model is run with the current Panama Canal capacity, the estimated shuttle train rates, and the currently approved 2013 toll rates for dry bulk vessel transiting the canal, as well as the 2011 trade flow quantity data.

Initially, the base model is being compared to conditions after the PCE is completed to examine what changes occur in the transportation of soybeans, under the same Panama Canal toll rates. First, this comparative analysis between current canal conditions and post PCE is done by subtracting the intercept term in the ocean shipping rate by the associated vessel-size dummy variable coefficient. This represents the lower shipping costs associated with economies of scale due to the increase in vessel capacity for the hauling of soybeans, foreshadowing the Panama Canal's ability to handle larger ships. Second, the Panama Canal route has a constraint for how many tons of soybeans they can actually handle, which is determined from histortical data of the Panama Canal Authority. The constrained volume is then compared to a Panama Canal with no constraints and the ability to handle larger vessels.

Afterwards, Panama Canal Expansion is comparatively analyzed by changing the toll rates to determine the sensitivity of the flow of shipment quantities, as well as the associated transportation costs of the soybean market. The toll rates are increased and decreased to examine these results within the model. As stated earlier in this thesis, these changes in toll rates are used to try and determine the toll rate at which the Panama Canal Authority will maximize their revenue for tolls collected by soybean shipments transiting the canal. By also changing the toll rates this study determines what the newly expanded canal's point elasticity of soybeans shipped through the canal relative to the toll rate.

The base and alternative models are minimized as follows:

The base model – the current panama canal capacity with the existing toll rate.

PCE model – the expanded canal capacity with the existing toll rate.

Model 1 - the expanded canal capacity with a toll rate of \$0.37/ton.

Model 2 – the expanded canal capacity with a toll rate of \$1.37/ton.

Model 3 – the expanded canal capacity with a toll rate of \$2.37/ton.

Model 4 – the expanded canal capacity with a toll rate of \$3.37/ton.

Model 5 – the expanded canal capacity with a toll rate of \$5.37/ton.

Model 6 – the expanded canal capacity with a toll rate of \$6.37/ton.

Model 7 – the expanded canal capacity with a toll rate of \$7.37/ton.

Model 8 – the expanded canal capacity with a toll rate of \$8.37/ton.

CHAPTER 5. EMPIRICAL RESULTS

This chapter presents the results found in regards to the trade flows and transportation costs associated with soybeans under the different predefined scenarios. The results are also used to comparatively analyze the effects of the Panama Canal Expansion on the U.S. soybean market.

Base Case and PCE

The comparative results for the base case model and the model including the expanded Panama Canal, with the same toll rates for each model, shows a significant impact on the quantity of soybeans shipped through the canal, but also a large reduction in the overall cost of transportation at a difference of $456 million. At the current toll rate of $4.37/ton, 23 million tons of soybeans that are shipped through the current Panama Canal, while 25.4 million tons of soybeans transit the canal from the Atlantic Ocean to the Pacific Ocean when the Panama Canal expands. Theoretically, expectations would be that more soybeans would be shipped through the Panama Canal after expansion due to the ability to handle vessels twice the size of the current canal system, which in turn leads to less expensive ocean freight rates. Those theories held true in the model runs as an expanded Panama Canal increased the number of soybeans transiting the canal by 2.4 million tons as compared to the base model.

The transportation of soybeans is more expensive than one may think, with roughly $10 billion spent on the transportation of soybeans from producing regions to domestic consuming regions, as well as, exports to the importing regions. The U.S. shipped a total of 23 million tons of U.S. soybeans through the Panama Canal in the base case and 25.4 million tons in the PCE model. The PCE scenario featured lower ocean shipping rates, and also lowered the overall shipping costs of soybeans by about $456 million (a reduction of about 5 percent). Roughly 50 percent of all U.S. soybean exports were shipped through the Panama Canal to the Asian markets in the base case scenario, while that increased by 6 percent post PCE to 56 percent. The costs decrease even though the volume increases and the PCA's revenues increase.

Table 5.1. Tons of Soybeans Shipped from Export Port to Importing Region.

Export Port	Importing Region	Base	PCE
ROSARIO	CHINA	10,898,539	10,898,539
MANAUS	N-EURO	10,183,289	12,574,198
MANAUS	S-EURO	61,197	61,197
MANAUS	MIDEAST	639,666	639,666
MANAUS	N-AFRIC	463,546	463,546
PARANA	CHINA	19,548,318	17,157,409
PARANA	KOREA	579,234	579,234
PARANA	TAIWAN	808,386	808,386
PARANA	SE-ASIA	2,544,215	2,544,215
TACOMA	CHINA	5,400,000	5,400,000
PLAND	CHINA	4,996,123	4,996,123
HOUSTON	MEXICO	2,000,000	2,000,000
NEWORL	CHINA	14,602,572	16,993,481
NEWORL	MEXICO	1,639,226	1,639,226
NEWORL	JAPAN	3,108,428	3,108,428
NEWORL	KOREA	669,000	669,000
NEWORL	TAIWAN	1,660,000	1,660,000
NEWORL	SE-ASIA	2,960,000	2,960,000
NEWORL	S-AMER	658,876	658,876
NEWORL	S-EURO	844,909	558,869
NEWORL	C-AMER	264,715	264,715
NEWORL	MIDEAST	750,000	-
NEWORL	CARIB	155,815	155,815
NEWORL	N-AFRIC	1,354,869	-
TOLEDO	N-EURO	1,500,000	1,500,000
NORFOLK	N-EURO	2,458,909	-
NORFOLK	S-EURO	541,091	-
NORFOLK	MIDEAST	-	750,000
NORFOLK	N-AFRIC	-	1,354,869

Table 5.1. is comparing the amount of soybeans in tons shipped out of export ports to the importing regions in the base model compared to the PCE model. In the PCE model New Orleans quits shipping to the Middle East and North Africa because it is able to ship through the Panama Canal due to the canal's increased handling capacity. The Atlantic port of Norfolk picks up these shipments to the Middle East and Northern Africa, but a majority of the change is deferred between New Orleans and the Brazilian ports.

Table 5.2. Domestic Shipments to Export Port.

Producing Region	**Export Port**	**Base**	**PCE**	**$3.37/ton**	**$2.37/ton**	**$7.37/ton**
ARG	**ROSARIO**	10898539	10898539	10898539	10898539	10898539
BRZ	**MANAUS**	11347699	13738607	13738607	13738607	10806607
BRZ	**PARANA**	23480153	21089245	21089245	21089245	24021245
AL	**NEWORL**	353135	353135	353135	353135	353135.3
AR1	**NEWORL**	78686	78686	78686	78686	78685.7
AR2	**NEWORL**	3531538	3531538	3531538	3531538	3531538
AR3	**NEWORL**	29458	29458	29458	29458	29457.7
DE	**NORFOLK**	198266	198266	198266	198266	198266.5
FL	**NEWORL**	23119	23119	23119	23119	23118.98
IL1	**NEWORL**	5116829	5116829	5864000	7428822	5116829
IL2	**NEWORL**	5661657	5661657	5661657	5661657	5661657
KS2	**HOUSTON**	1683663	1683663	1683663	1683663	1683663
KS3	**HOUSTON**	201625	201625	201625	201625	201625.2
LA	**NEWORL**	1136914	1136914	1136914	1136914	1136914
MD	**NORFOLK**	538637	538637	538637	538637	538637.2
MI	**TOLEDO**	1500000	1500000	1500000	1500000	1500000
MN1	**TACOMA**	1756958	1686328	1686328	1686328	2566141
MN1	**PLAND**	809182	879813	879813	879813	
MS	**NEWORL**	2237074	2237074	2237074	2237074	2237074
NJ	**NORFOLK**	91876	91876	91876	91876	91875.85
NC	**NORFOLK**	1405907	1405907	1405907	1405907	1405907
ND1	**TACOMA**	3565360	3565360	3565360	3565360	2833859
ND1	**PLAND**	0	0	0	0	731500.7
ND2	**TACOMA**	77681	77681	77681	77681	0
ND2	**PLAND**	0	0	0	0	77681.47
PA	**NORFOLK**	195323	195323	195323	195323	0
SD1	**PLAND**	4116310	4116310	1856988	292166	195322.9
SD2	**PLAND**	70631	70631	70631	70631	4116310
TN	**NEWORL**	0	0	1512151	1512151	70630.86
TX	**HOUSTON**	114711	114711	114711	114711	114711.5
VA	**NORFOLK**	569990	569990	569990	569990	569990.3

Table 5.2. shows the domestic movements from production regions to export ports given different model scenarios. Domestic movements of soybeans to export ports are unchanged by the Panama Canal expansion as the only change that occurs is in Minnesota. However it only changes shipments from Tacoma and ships them to Portland instead. This stands to reason as supply and demand are fixed. Although soybeans that are coming out of export ports remain the same where soybeans are being shipped to changes from Base to PCE models as can be obseved in Table 5.1. Referring to Figure 2.4. in Chapter 2, the only gain of soybeans from Eastern South Dakota to the Gulf in this model occurs if the toll rate falls after expansion by a dollar or more. However, further requirment for Eastern South Dakota soybean gains through the Gulf is that the Mississippi river system is not updated and continues to handle roughly the same amount of soybeans year in and year out. So, given the domestic flow of soybeans to export ports in the U.S. it shows that domestic transportation outcomes are insensitive to the Panama Canal expansion and toll rates.

Table 5.3. Shadow Price at Constrained Ports.

(per Ton)	Panama Canal	PNW	Norfolk	Great Lakes	Houston
Base Model	$ 1.80	$ 0.45	$ 43.24	$ 70.32	$ 16.38
PCE Model	$ -	$ 0.45	$ 43.24	$ 70.32	$ 19.13

Table 5.3. reflects the shadow price at constrained export ports under the base and PCE models. The shadow price at the current Panama Canal is a $1.80, indicating that if the Panama Canal handles one more ton of soybeans it reduces the overall shipping costs by $1.80/ton. There is no shadow price at the Panama Canal in the PCE model because after expansion the canal is no longer constrained. A point of interest is that the shadow price at the Panama Canal is higher

than that at the PNW, meaning that once the canal expansion is completed there should not only be more shipments going to the Gulf through the canal, but it will also cost about one-fourth as much as shipping out of the PNW. Lastly, the exports out of Houston are expected to decrease the overall cost after expansion, whereas the other constrained export ports will remain the same. This is due mostly to the fact that Houston is in closer proxmity to the Panama Canal and will potentially incur savings and more shipments due to the PCE. As for PNW, Norfolk and Great Lake ports being the same before and after expansion is because those ports are not shipping through the canal as seen in Table 5.5., so they are not affected such as Houston. Norfolk and Great Lake ports have a considerably higher shadow price compared to the other export ports[1][2][3]. However, these export ports travel a considerably shorter distance to get from producing regions to the export port by way of domestic transportation. In addition, Norfolk and Great Lake ports are shipping most soybeans to Europe, which is a considerably shorter distance when compared to the distances traveled from the other export ports. Therefore, by relaxing the constraint one unit, the optimal solution will use the lowest transportation cost by displacing the highest transportation cost and since transportation rates are a function of distance, the shadow price could be that large.

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[1] This is potentially due to rounding error.

[2] This may be a result of port capacity definitions. An AMS study from (Taylor, 2013), was used to determine capacity constraints. The percent share of U.S. soybeans shipped from those ports found by (Taylor, 2013), was used with the 3-year average of export supply and calculated to approximately the same percent share of U.S. soybean exports going out of those ports. However, Norfolk and the Great Lake ports are closer to producing regions that may make those ports optimal solutions, but due to the potential of being over constrained may result in the high shadow prices.

[3] Lastly, having fixed supply and demand would also attribute to the same shadow prices before and after expansion. The Gulf port is not exporting anymore soybeans between the base and PCE models, it is only rerouting more through the Canal, while the Northern Brazilian port of Manaus picks up some of those exports to Europe.

Toll Rate Changes

The changes in toll rates at the Panama Canal influence international trade flows from export ports to importing countries through the canal. As the canal has a sizeable role in soybean imports in the East Asian countries, the changes in toll rates influence trade flows prominently to these countries.

The results from the changes in the Panama Canal toll rates upon the quantity of soybeans shipped through the canal to the Asian market is seen below in Table 5.1. As noted in the previous section the total quantity traded through the canal after the expansion, is 25.4 million tons with a current toll rate of $4.37/ton.The amount of U.S. soybeans shipped through the canal at the toll rate of $0.37/ton is 31.5 million tons of soybeans. That is a 24 percent increase from the quantity flowing through the canal at the current toll rate.

Table 5.4. Quantity of Soybeans Shipped from Atlantic to Pacific Through the Panama Canal to Selected Importing Countries.

Toll Rate	China	Japan	S. Korea	Taiwan	SE Asia	Total
			1000 Tons			
$0.37/ton scenario	23,086	3,108	670	1,660	2,960	31,484
$1.37/ton scenario	21,456	3,108	670	1,660	2,960	29,854
$2.37/ton scenario	20,818	3,108	670	1,660	2,960	29,216
$3.37/ton scenario	19,253	3,108	670	1,660	2,960	27,651
Current 2013 ($4.37/ton)	16,993	3,108	670	1,660	2,960	25,391
$5.37/ton scenario	16,993	3,108	670	1,660	2,960	25,391
$6.37/ton scenario	16,993	3,108	670	1,660	2,960	25,391
$7.37/ton scenario	14,061	3,108	670	1,660	2,960	22,459
$8.37/ton scenario	11,083	3,108	670	1,660	2,960	19,481

As shown in Table 5.4., China's imports of U.S. soybeans through the canal are the most sensitive to changes in the toll rate – China's imports fall by half as the toll rate changes from lowest to highest (column 1). China is the largest importer of soybeans and that is why they are also the most sensitive to changes in the toll rate at the Panama Canal.

This sensitivity can be attributed to the linear programming methodology as well, because once there is lower overall transportation cost, all of the supply of soybeans will be shipped out of that lower rate port, at least until that port becomes constrained or the amount of soybeans coming from that producing region are exhausted. Table 5.5. shows the quantity of soybeans shipped out of the Gulf ports through the canal.

Table 5.5. Quantity of Soybeans Transiting the Panama Canal from Export Region.

Toll Rate	Gulf	PNW	Atlantic	Great Lakes	Argentina	Brazil N.	Brazil S.
	1000 Tons						
$0.37/ton scenario	29,854	-	-	-	-	1,630	-
$1.37/ton scenario	29,854	-	-	-	-	-	-
$2.37/ton scenario	29,215	-	-	-	-	-	-
$3.37/ton scenario	27,650	-	-	-	-	-	-
Current 2013 ($4.37/ton)	25,391	-	-	-	-	-	-
$5.37/ton scenario	25,391	-	-	-	-	-	-
$6.37/ton scenario	25,391	-	-	-	-	-	-
$7.37/ton scenario	22,459	-	-	-	-	-	-
$8.37/ton scenario	19,480	-	-	-	-	-	-

As shown in Table 5.4. & 5.5., the shipments of U.S. soybeans that are coming out of the port of New Orleans are more sensitive than the Atlantic ports and ports located along the St. Lawerence Seaway, to changes in the Panama Canal toll. This is due to the fact that the Great Lakes and Atlantic ports are shipping their soybean exports to Europe and not sending any through the Panama Canal. Also, Nothern Brazil exports only become competitive in shipping soybeans through the Panama Canal at a toll rate of $0.37/ton, but are otherwise uncompetitive with the U.S. in regards to shipping their soybeans through the canal. Soybean exports by port are also sensitive on the west coast ports to changes in the toll rate, but not as sensitive as the Gulf ports as seen in Table 5.6.: as the toll rate increases, PNW increases shipments of soybeans to Asian markets from 6,500 tons.

Table 5.6. Quantity of Soybeans Shipped Out of Export Port.

Toll Rate	Gulf	PNW	Atlantic	Great Lakes	Argentina	Brazil N.	Brazil S.
	1000 Tons						
$0.37/ton scenario	34,500	6,564	3,000	1,500	10,899	16,000	18,828
$1.37/ton scenario	34,500	6,564	3,000	1,500	10,899	14,370	20,458
$2.37/ton scenario	34,493	6,572	3,000	1,500	10,899	13,739	21,089
$3.37/ton scenario	30,928	8,137	3,000	1,500	10,899	13,739	21,089
Current 2013 ($4.37/ton)	28,668	10,396	3,000	1,500	10,899	13,739	21,089
$5.37/ton scenario	28,668	10,396	3,000	1,500	10,899	13,739	21,089
$6.37/ton scenario	28,668	10,396	3,000	1,500	10,899	13,739	21,089
$7.37/ton scenario	28,668	10,396	3,000	1,500	10,899	10,807	24,021
$8.37/ton scenario	28,668	10,396	3,000	1,500	10,899	7,828	27,000

The ports located within the Great Lakes as well as the Atlantic ports remain insensitive to changes in the canal toll rates as the majority of their soybean exports are shipped to Europe, Northern Africa, Central America, and South America where the ocean shipments are not affected by the toll rates, because ocean transportation costs are unchanged since those export movements are not going through the canal. Overall, Table 5.6. shows that the main flow for increased Gulf shipments with lower tariffs is due to reduced PNW exports, on a one-for-one basis.

The results from all the different model scenario were taken to find the maximum point of toll revenues against the toll rate. This inflection point is where the Panama Canal Authority would most likely maximize their toll revenues and could potentially be an indication of a future toll rate per ton for soybeans that are being exported through the Panama Canal, once the PCE is completed. The toll revenue at given toll rates is depicted in Figure 5.1.:

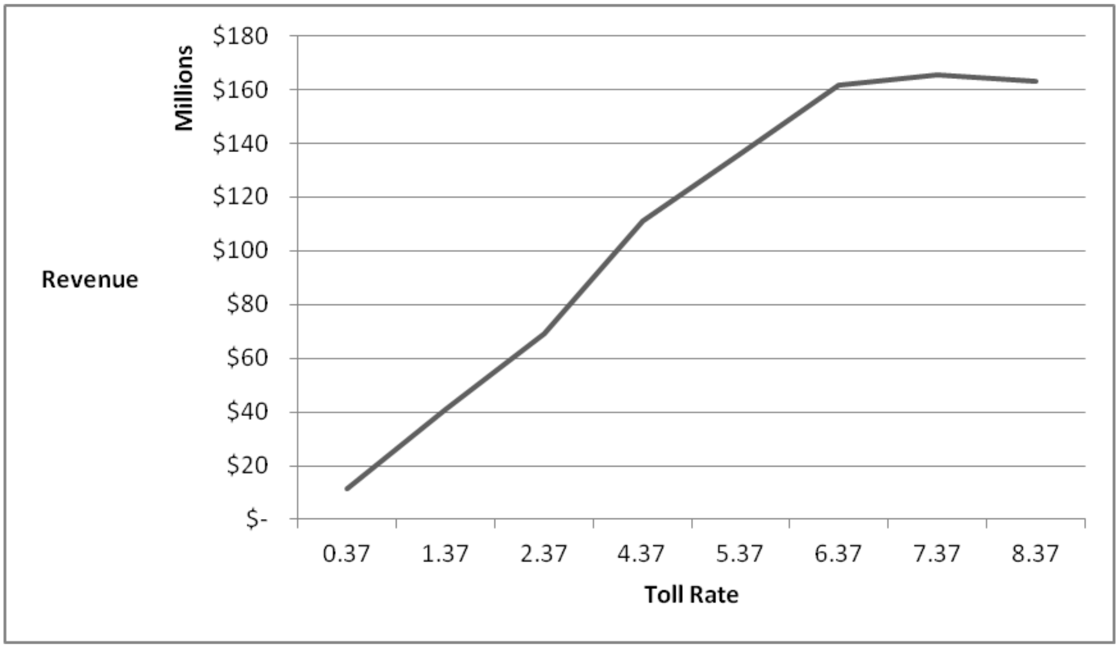

Figure 5.1. Panama Canal Toll Revenue.

In Figure 5.1., the toll rate, where toll revenues for U.S. soybean exports transiting the canal are maximized, was found to be between $7.37/ton and $8.37/ton. This is close to double the currently approved 2013 Panama Canal Authority toll rate for dry bulk vessels. The actual optimum toll rate was calculated to be $7.43/ton.

The elasticities of U.S. soybeans shipped through the canal in relation to the different toll rates associated with those quantities were also found. The revenue elasticities with respecct to the toll rate for U.S. soybeans shipped through the canal turned out to be inelastic.This relationship is shown in Figure 5.2.

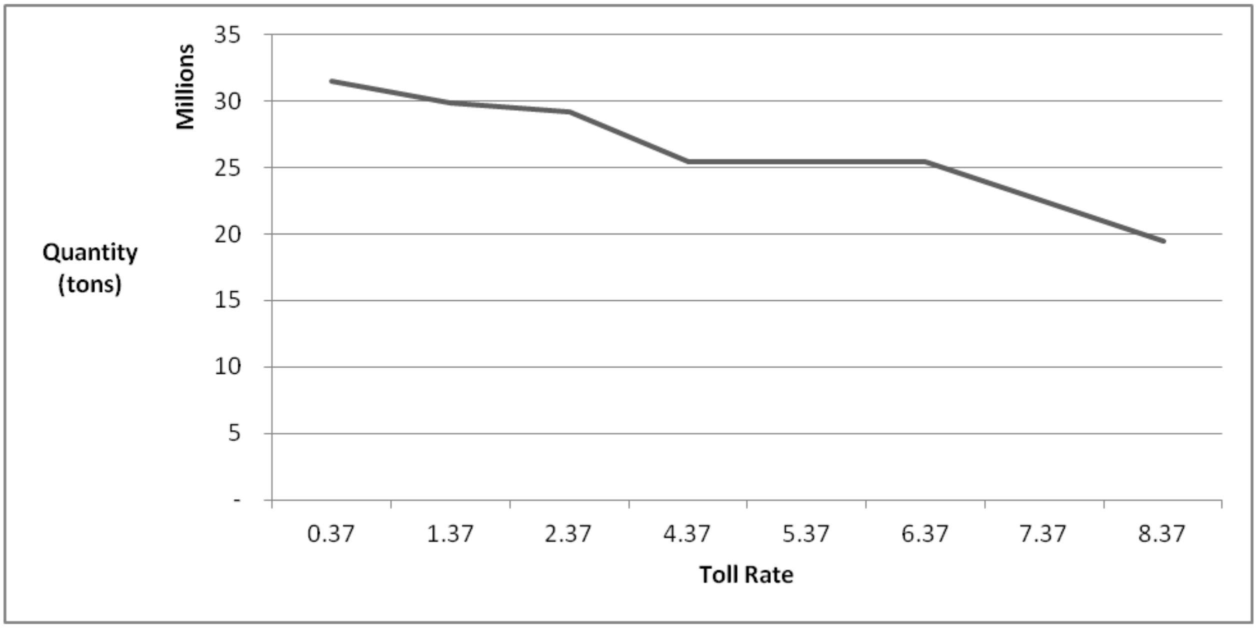

Figure 5.2. U.S. Shipments of Soybeans Through the Panama Canal Versus Toll Rate.

Figure 5.2. gives a good representation of why the point elasticities are negative, because as toll rates go up the quantity shipped throught the canal will go down. The average across all point elasticities from toll rates $0.37 to $8.37 was -0.27, suggesting revenue increases from toll increases. Given a dollar increase in the Panama Canal toll rate the quantity of U.S. soybeans

shipped through the canal would decrease unproportionately to the increase in tolls. This would mean that soybeans shipped through the canal, while still sensitive to changes in the toll rate, are not as sensitive to toll rate changes if the relationship between percentage change in quantity over the percentage change in the toll rate were more elastic such as -2.0. Lastly, the point elasticity from the toll rates of $7.37 to $8.37 was -0.98, suggesting that revenues can no longer increase as the tariff increases.

CHAPTER 6. SUMMARY AND CONCLUSIONS

The transportaiton of U.S. agricultural commodities will continue to be a topic of interest, especially when looking at soybeans because it is the third largest commodity traded globally. The reason for continuous studies on the topic of transportation of agricultural commodities, is because soybean production takes place in rural areas and more often than not are demanded in urban areas where the grains and oilseeds are milled and crushed for multitude of different uses. The bulkiness of shipping soybeans and the distances soybeans must travel to get to crushing locations or importing countries is pretty far with very high transportation costs. With China's massive increase in demand for soybeans, China must turn to imports from producing countries like the U.S., Brazil, or Argentina to meet China's growing demand for soybeans.

The Panama Canal is being expanded to reduce shipping congestions, due to the increase in global trade across countries.The rise in world trade has led to the greater cargo hauling of ocean vessels, and the increase in the number these larger vessels being manufactured . Fleets of post-Panamax ships continue to rise while until recently had no short cut option of transiting the Panama Canal and would otherwise have to navigate an extra 12,000 miles of ocean to get to where they were heading.

The objective of this study is to evaluate the impact of the Panama Canal Expansion on the U.S. flow of soybeans from producing regions in the U.S. to its ports for export, with special interest in the flow of soybeans to the East Asian market. Specific objectives of this study are to determine the toll rate at which the Panama Canal Authority will maximize their toll revenues for U.S. soybeans, and to analyze the impact of the canal expansion on soybean shipments from U.S. producing regions to ports for export.

A spatial optimization model was developed based on a mathematical programming algorithm to conduct this study. The model minimizes all transportation costs associated with the transportation of U.S. soybeans, in order to get them from the production regions to the domestic consuming regions and then also from the production regions to the export ports and from export ports to the foreign importing countries. The objective function is minimized subject to a system of linear constraints.

Summary

The base model compared to the estimiation of transportatin costs associated with U.S. soybeans after the Panama Canal Expansion showed that there would be a change in the quantity of soybeans shipped through the canal and the quantity would increase by 2.4 million tons. The increased capacity of the canal would also reduce congestion and lower ocean transportation costs reducing the objective function by $456 million.

Once the Panama Canal is expanded the model evaluated the effectsof increases and decreases in the toll rates for transiting the canal, on soybean export shipments. The findings concluded that the Gulf Ports were most sensitive to changes in the toll rate, and that the ports capturing the Gulf's sensitivity to the toll rates were captured by either the PNW or Brazil. Results found that the ports located on the St. Lawerence Seaway and Atlantic Coast were constant and unaffected by the toll rates at the Panama Canal for the shipment of U.S. soybeans.

The toll rates were then increased and decreased to determine the point at which toll revenue was maximized. The toll rate where toll revenue was maximized was found to be $7.43/ton nearly doubling the current canal tariff rate. Elasticities were derived and found to be inelastic for soybean shipments transiting through the Panama Canal.

Conclusions

The base case of current canal conditions compared to the PCE for U.S. soybeans shipped through the canal were found to increase the quantity shipped through the canal by 6 percent and decrease transportation costs by 5 percent between base case model and PCE model.

The predicted toll rate of $7.43/ton for soybeans transiting the Panama Canal, where the Panama Canal Authority is maximizing its revenue may seem high, but is most likely because the reduced ocean shipping rates are so much lower than the rail rates to ship the soybeans to the west coast by way of inland transportation, that shippers are willing to pay that much in tolls to still transit the canal. Also, looking at the elasticities at the canal an inelastic demand would suggest that shipping companies do not care how expensive it is until it reaches around $7/ton.

The Panama Canal expansion has a marginal effect shipment quantities leaving the U.S. export ports or transiting the Panama Canal. The overall minimized objective function decreased the whole models transportation cost of soybeans by $456 million or 5 percent once the canal was expanded, even though trade volume expanded by 2.4 million tons. Changing toll rates at the Panama Canal affected the Gulf Ports and PNW the most. These competitive ports were the most sensitive to changes in the toll rate, because the model would ship as much soybeans to the export port with the lowest cost from the producing regions that were shipping beteween these two ports. One dollar changes in the Panama Canal toll rate would shift the amount of soybeans shipped to China from either the Gulf or PNW.

The ports located upon the Great Lakes and Atlantic coast were insensitive to changes in the toll rate and exported the same quantities of soybeans regardless of the toll rate. This is because the majority of these two portswere shipping to Europe, Northern Africa, Central

America, and some South American countries, which were unaffected by the Panama Canal toll rates.

Almost all exports headed to China came out of the PNW, Gulf, Southern Brazil, and Argentina. Increases in the Panama Canal toll rate did see more soybeans being transported by rail out to the PNW, but the PNW export response was not very sensitive to those toll rate changes.

Two notes of interest regarding the role of northern states in the PCE. First, both North Dakota producing regions shipped all of their soybeans to Tacoma for export. Second the Port of Tacoma captured all of Portland’s shipments to Eastern Asia by having a marginally lower overall tranportation costs of a $1.30 or less.

One limitation of this study is the focus on only one commodity, soybeans; future study should include other agricultural commodities. The next limitation would be linear programming. Future studies should include quadratic programming as supply and demand are rarely fixed. Also, quadratic programming allows for a better incorporation of price and profit data, which drives the transportation of agricultural goods. Lastly, the role of vessels idled waiting time in the Panama Canal ques deserves some attention.

In preliminary simulations, a delay cost was the only thing determining the effects of the PCE. Now a constraint that limits the amount of soybeans transiting the Panama Canal represents how much they can handle. The constraint was added with the delay cost because the time cost did not affect the model solution. Further investigation done in regards to the delay costs due to the congestion at the Panama Canal[4].

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[4] Operational costs for a Panamax vessel are about $0.24 per ton per day (Bockmann, 2013). After calculating the operating cost per ton per day, the average wait time at the canal to transit the canal is roughly 4 days. So, α was entered into the model at $5.33 ($0.96/ton delay cost + $4.37/ton toll rate) per ton under the current Panama Canal conditions. With the PCE, the ocean freight rate decreased and the delay costs were eliminated with more capacity and large vessels. So estimated Soybeans shipments through the Panama Canal after PCE are about the same as base solution shipments.. The threshold for which the soybean quantities shipped through the canal would change due to the delay cost was when the delay cost was equal to $2.73/ton. This means that vessels would sit at the Panama Canal for roughly 12 days before deciding to use a different route, according to the model. This shows the value of the Panama Canal to ocean shipping companies.

However, there may also be an opportunity cost (or foregone profits) associated with the wait time at the Panama Canal. To get an idea of profits forgone let me calculate the profits that would have been earned in a U.S. – Central American haul in lieu of the 4 day wait at the Panama Canal. Profits for a U.S. – Central American haul are revenues minus costs. For operating costs, use Bockmann's (2013) estimates of $0.24 per ton per day for variable (wages & energy). For revenues use my estimated distance-rate function, T = 14.83 + .0043. The distance is 810 miles from the Gulf to Veracruz, Mexico. Then the unit revenue for transport is T = $18.31/ton. So, Profits = ($18.31/ton – ($0.24/ton/day * 4 days)) = $17.35/ton. Since a U.S. – Central American trip takes about 4 days the foregone daily profit is $4.34 per ton per day. So, the economic transport costs through the canal may be somewhat higher than estimated by the model. On the other-hand if the shipper cannot procure a back-haul from Mexico it may not be worth the time.

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APPENDIX A. BASE MODEL – PRODUCTION REGIONS TO EXPORT PORT FLOWS

Base Model - Production Regions to Export Port Flows

	Export Port										
Producing Region	ROSARIO	MANAUS	PARANA	TACOMA	PLAND	LB	HOUSTON	NEWORL	TOLEDO	NORFOLK	TOTAL
ARG	10,898,539	-	-	-	-	-	-	-	-	-	10,898,539
BRA	-	11,347,699	23,480,153	-	-	-	-	-	-	-	34,827,852
AL	-	-	-	-	-	-	-	353,135	-	-	353,135
AR1	-	-	-	-	-	-	-	78,686	-	-	78,686
AR2	-	-	-	-	-	-	-	3,531,538	-	-	3,531,538
AR3	-	-	-	-	-	-	-	29,458	-	-	29,458
DE	-	-	-	-	-	-	-		-	198,266	198,266
FL	-	-	-	-	-	-	-	23,119	-		23,119
GA	-	-	-	-	-	-	-	-	-	-	-
IL1	-	-	-	-	-	-	-	5,116,829	-	-	5,116,829
IL2	-	-	-	-	-	-	-	5,661,657	-	-	5,661,657
IN1	-	-	-	-	-	-	-	-	-	-	-
IN2	-	-	-	-	-	-	-	-	-	-	-
IN3	-	-	-	-	-	-	-	-	-	-	-
IA1	-	-	-	-	-	-	-	-	-	-	-
IA2	-	-	-	-	-	-	-	-	-	-	-
IA3	-	-	-	-	-	-	-	-	-	-	-
KS1	-	-	-	-	-	-	-	-	-	-	-
KS2	-	-	-	-	-	-	1,683,663	-	-	-	1,683,663
KS3	-	-	-	-	-	-	201,625	-	-	-	201,625
KY	-	-	-	-	-	-	-	-	-	-	-
LA	-	-	-	-	-	-	-	1,136,914	-	-	1,136,914
MD	-	-	-	-	-	-	-	-	-	538,637	538,637
MI	-	-	-	-	-	-	-	-	1,500,000	-	1,500,000
MN1	-	-	-	1,756,958	-	-	-	-	-	-	1,756,958
MN2	-	-	-	-	809,182	-	-	-	-	-	809,182
MS	-	-	-	-	-	-	-	2,237,074	-	-	2,237,074
MO1	-	-	-	-	-	-	-	-	-	-	-
MO2	-	-	-	-	-	-	-	-	-	-	-
NE1	-	-	-	-	-	-	-	-	-	-	-
NE2	-	-	-	-	-	-	-	-	-	-	-
NE3	-	-	-	-	-	-	-	-	-	-	-
NJ	-	-	-	-	-	-	-	-	-	91,876	91,876
NY	-	-	-	-	-	-	-	-	-	-	-
NC	-	-	-	-	-	-	-	-	-	1,405,907	1,405,907
ND1	-	-	-	3,565,360	-	-	-	-	-	-	3,565,360
ND2	-	-	-	77,681	-	-	-	-	-	-	77,681
OH1	-	-	-	-	-	-	-	-	-	-	-
OH2	-	-	-	-	-	-	-	-	-	-	-
OH3	-	-	-	-	-	-	-	-	-	-	-
OK	-	-	-	-	-	-	-	-	-	-	-
PA	-	-	-	-	-	-	-	-	-	195,323	195,323
SC	-	-	-	-	-	-	-	-	-	-	-
SD1	-	-	-	-	4,116,310	-	-	-	-	-	4,116,310
SD2	-	-	-	-	70,631	-	-	-	-	-	70,631
TN	-	-	-	-	-	-	-	-	-	-	-
TX	-	-	-	-	-	-	114,711	-	-	-	114,711
VA	-	-	-	-	-	-	-	-	-	569,990	569,990
WV	-	-	-	-	-	-	-	-	-	-	-
WI	-	-	-	-	-	-	-	-	-	-	-

APPENDIX B. PCE MODEL – PRODUCTION REGIONS TO EXPORT PORT FLOWS

PCE Model - Production Regions to Export Port Flows

	Export Port										
Producing Region	ROSARIO	MANAUS	PARANA	TACOMA	PLAND	LB	HOUSTON	NEWORL	TOLEDO	NORFOLK	TOTAL
ARG	10,898,539	-	-	-	-	-	-	-	-	-	10,898,539
BRA	-	13,738,607	21,089,245	-	-	-	-	-	-	-	34,827,852
AL	-	-	-	-	-	-	-	353,135	-	-	353,135
AR1	-	-	-	-	-	-	-	78,686	-	-	78,686
AR2	-	-	-	-	-	-	-	3,531,538	-	-	3,531,538
AR3	-	-	-	-	-	-	-	29,458	-	-	29,458
DE	-	-	-	-	-	-	-		-	198,266	198,266
FL	-	-	-	-	-	-	-	23,119	-		23,119
GA	-	-	-	-	-	-	-	-	-	-	-
IL1	-	-	-	-	-	-	-	5,116,829	-	-	5,116,829
IL2	-	-	-	-	-	-	-	5,661,657	-	-	5,661,657
IN1	-	-	-	-	-	-	-	-	-	-	-
IN2	-	-	-	-	-	-	-	-	-	-	-
IN3	-	-	-	-	-	-	-	-	-	-	-
IA1	-	-	-	-	-	-	-	-	-	-	-
IA2	-	-	-	-	-	-	-	-	-	-	-
IA3	-	-	-	-	-	-	-	-	-	-	-
KS1	-	-	-	-	-	-	-	-	-	-	-
KS2	-	-	-	-	-	-	1,683,663	-	-	-	1,683,663
KS3	-	-	-	-	-	-	201,625	-	-	-	201,625
KY	-	-	-	-	-	-	-	-	-	-	-
LA	-	-	-	-	-	-	-	1,136,914	-	-	1,136,914
MD	-	-	-	-	-	-	-	-	-	538,637	538,637
MI	-	-	-	-	-	-	-	-	1,500,000	-	1,500,000
MN1	-	-	-	1,686,328	879,813	-	-	-	-	-	2,566,141
MN2	-	-	-	-	809,182	-	-	-	-	-	809,182
MS	-	-	-	-	-	-	-	2,237,074	-	-	2,237,074
MO1	-	-	-	-	-	-	-	-	-	-	-
MO2	-	-	-	-	-	-	-	-	-	-	-
NE1	-	-	-	-	-	-	-	-	-	-	-
NE2	-	-	-	-	-	-	-	-	-	-	-
NE3	-	-	-	-	-	-	-	-	-	-	-
NJ	-	-	-	-	-	-	-	-	-	91,876	91,876
NY	-	-	-	-	-	-	-	-	-	-	-
NC	-	-	-	-	-	-	-	-	-	1,405,907	1,405,907
ND1	-	-	-	3,565,360	-	-	-	-	-	-	3,565,360
ND2	-	-	-	77,681	-	-	-	-	-	-	77,681
OH1	-	-	-	-	-	-	-	-	-	-	-
OH2	-	-	-	-	-	-	-	-	-	-	-
OH3	-	-	-	-	-	-	-	-	-	-	-
OK	-	-	-	-	-	-	-	-	-	-	-
PA	-	-	-	-	-	-	-	-	-	195,323	195,323
SC	-	-	-	-	-	-	-	-	-	-	-
SD1	-	-	-	-	4,116,310	-	-	-	-	-	4,116,310
SD2	-	-	-	-	70,631	-	-	-	-	-	70,631
TN	-	-	-	-	-	-	-	-	-	-	-
TX	-	-	-	-	-	-	114,711	-	-	-	114,711
VA	-	-	-	-	-	-	-	-	-	569,990	569,990
WV	-	-	-	-	-	-	-	-	-	-	-
WI	-	-	-	-	-	-	-	-	-	-	-

APPENDIX C. BASE MODEL – EXPORT PORT TO IMPORTING REGION FLOWS

Base Model - Export Port to Importing Region Flows

Export Port	Importing Region													
	CHINA	MEXICO	JAPAN	S-KOREA	TAIWAN	SE-ASIA	S-AMERICA	N-EUROPE	S-EUROPE	C-AMERICA	MIDDLE-EAST	CARIBBEAN	N-AFRICA	TOTAL
ROSARIO	10,898,539	-	-	-	-	-	-	-	-	-	-	-	-	10,898,539
MANAUS	-	-	-	-	-	-	-	10,183,289	61,197	-	639,666	-	463,546	11,347,699
PARANA	19,548,318	-	-	579,234	808,386	2,544,215	-	-	-	-	-	-	-	23,480,153
TACOMA	5,400,000	-	-	-	-	-	-	-	-	-	-	-	-	5,400,000
PLAND	4,996,123	-	-	-	-	-	-	-	-	-	-	-	-	4,996,123
LB	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HOUSTON	-	2,000,000	-	-	-	-	-	-	-	-	-	-	-	2,000,000
NEWORL	14,602,572	1,639,226	3,108,428	669,000	1,660,000	2,960,000	658,876	-	844,909	264,715	750,000	155,815	1,354,869	28,668,410
TOLEDO	-	-	-	-	-	-	-	1,500,000	-	-	-	-	-	1,500,000
NORFOLK	-	-	-	-	-	-	-	2,458,909	541,091	-	-	-	-	3,000,000

APPENDIX D. PCE MODEL – EXPORT PORT TO IMPORTING REGION FLOWS

PCE Model - Export Port to Importing Region Flows

	Importing Region													
Export Port	CHINA	MEXICO	JAPAN	S-KOREA	TAIWAN	SE-ASIA	S-AMERICA	N-EUROPE	S-EUROPE	C-AMERICA	MIDDLE-EAST	CARIBBEAN	N-AFRICA	TOTAL
ROSARIO	10,898,539	-	-	-	-	-	-	-	-	-	-	-	-	10,898,539
MANAUS	-	-	-	-	-	-	-	12,574,198	61,197	-	639,666	-	463,546	13,738,607
PARANA	17,157,409	-	-	579,234	808,386	2,544,215	-	-	-	-	-	-	-	21,089,245
TACOMA	5,400,000	-	-	-	-	-	-	-	-	-	-	-	-	5,400,000
PLAND	4,996,123	-	-	-	-	-	-	-	-	-	-	-	-	4,996,123
LB	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HOUSTON	-	2,000,000	-	-	-	-	-	-	-	-	-	-	-	2,000,000
NEWORL	16,993,481	1,639,226	3,108,428	669,000	1,660,000	2,960,000	658,876	-	558,869	264,715	-	155,815	-	28,668,410
TOLEDO	-	-	-	-	-	-	-	1,500,000	-	-	-	-	-	1,500,000
NORFOLK	-	-	-	-	-	-	-	68,000	827,131	-	750,000	-	1,354,869	3,000,000