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Trouble at Old River: The Impact of a Mississippi River Avulsion on U.S. Soybean Exports

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Abstract

The Mississippi River transportation system provides relatively low transportation costs for bulk commodities, enhancing U.S. competitiveness in the world soybean market. The Mississippi River's urgency to change course and disrupt barge travel to the New Orleans Gulf Port Region puts this advantage in jeopardy. Using transportation costs of specific modes and routes to port of import destinations, we determine that a change in the river's course would lead to an overall 27.27% increase in total costs of shipping soybeans to Shanghai, Rotterdam, and Veracruz.

Keywords: avulsion, exports, intermodal transportation, Mississippi River, network optimization model, soybeans, transportation costs, transportation system, United States

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Introduction

Barge travel along the Mississippi River provides a competitive advantage for U.S. agricultural exports. The possibility of an avulsion—the natural displacement of an established river channel (Latrubesse, 2015; Smith and Rogers, 1999)—at the Old River Control Structure (ORCS) is gradually increasing as a result of several factors related to the deposition of alluvial sediments and severe weather.

The ORCS maintains water discharge capacity for the Atchafalaya and Mississippi Rivers at approximately 30% and 70%, respectively. Should severe flooding cause the structure to fail, the distribution of water for each river would interchange, causing the abandonment of the existing Mississippi River channel and the creation of a new course to the Gulf of Mexico via the Atchafalaya River. Should this avulsion occur, the disruption of U.S. shipping channels would create an immediate need to identify alternative routes and modes for moving U.S. goods, particularly bulk agricultural commodities such as soybeans. Longer-term issues include whether or how quickly the Mississippi River could be recaptured. If the avulsion were permanent, the form and speed at which transportation infrastructure along the "new" Mississippi River would be developed is not certain. Regardless of the outcome of these issues, the possibility of an avulsion threatens the U.S. competitive advantage in soybean trade.

This research determines the immediate impact of a Mississippi River avulsion on U.S. soybean trade and examines options for transporting soybeans via alternative transportation modes and routes. The specific objectives are to identify alternative soybean export routes based on the total transportation cost from U.S. supply points to foreign destinations, compare the least-cost alternatives of shipping soybeans to port of export destinations and final demand destinations before and after an avulsion, and provide implications for future policy and industry decisions.

Background

Brazil currently leads the world in soybean production and export market share, followed by the United States and Argentina. Although competition from other countries in the global market has increased, low transportation costs of soybeans, grain, and other oilseed crops allow the United States to retain a competitive advantage. The shipment of soybeans by barge to Mississippi Gulf ports relies on the accessibility of the Mississippi River to maintain a cost-efficient transportation system. An efficient transportation infrastructure—consisting of effective railroad, highway, and waterway systems—connects United States soybean producers to global markets (U.S. Soybean Export Council, 2015).

Before reaching markets, soybeans produced in the Midwest pass through a complex supply chain involving several options including local elevators, crushing facilities, and rail and barge terminals (Informa Economics, 2016). Typically, when harvested, soybeans not placed in on-farm storage are transported by truck to port of export facilities or shipped to nearby intermodal facilities (Informa Economics, 2016), including barge terminals and shuttle elevators. Soybeans destined for export are loaded onto barges and railcars and shipped to port of export facilities. Between

2007 and 2017, on average nearly 50% of soybeans produced in the United States was exported in bulk or containerized shipping through Mississippi Gulf and Pacific Northwest (PNW) ports.

The Mississippi River is responsible for most U.S. soybean exports. As shown by U.S. customs district data (Table 1), Gulf and West Coast ports accounted for over 90% of U.S. soybean exports, with the Gulf region accounting for over 65%. It is not surprising that the Gulf and West Coast regions are the dominant ports of export for product shipped to Asia, but the Gulf is also dominant in shipping product to Europe, the Middle East, and Africa. Although it would be logical for the Great Lakes and East Coast ports to capture more of these markets, the infrastructure and low transportation costs of shipping soybeans through the Gulf via the Mississippi River have contributed to the dominance of the Gulf region with respect to U.S. soybean exports.

Table 1. U.S. Soybean Export Quantities by Customs District, 2015–2019 Average (metric tons)

	East Coast	**Great Lakes**	**Gulf**	**West Coast**	**Other**	**Total**
Caribbean	62,655.9	0.0	38,857.9	350.6	4.4	101,868.7
Central America	365.3	13.6	345,086.2	1,227.2	0.0	346,692.3
East Asia	1,039,344.1	257,525.7	16,630,287.9	12,005,213.7	0.9	29,932,372.2
EU27+UK	185,132.3	269,320.8	5,248,220.4	12,010.8	0.0	5,714,684.3
Former Soviet Union-12	56,413.2	9,781.6	69,217.4	0.0	0.0	135,412.2
Middle East	62,682.2	85,701.9	698,034.8	50,938.0	0.0	897,356.9
North Africa	201,430.6	13,752.0	1,659,369.6	0.0	0.0	1,874,552.2
North America	1,663.1	430,817.9	4,209,332.5	7,878.7	49.0	4,649,741.2
Oceania	13.8	0.0	0.0	1,258.0	0.0	1,271.8
Other Europe	3.6	4,300.0	0.0	0.0	0.0	4,303.6
South America	52,267.0	20,695.4	1,212,385.2	6,133.3	0.0	1,291,480.9
South Asia	78,338.9	4,933.8	1,678,483.0	162,841.9	0.0	1,924,597.6
Southeast Asia	1,210,558.2	122,931.8	2,097,064.4	1,607,329.7	5.2	5,037,889.3
Sub-Saharan Africa	9.2	0.0	22,112.8	230.2	0.0	22,352.2
Total	2,950,877.4	1,219,774.5	33,908,452.2	13,855,412.1	59.5	51,934,575.6

Source: USDA/FAS Global Agricultural Trade System Database.

The Port of South Louisiana, a port region located between Convent and Westwago, Louisiana, typically services over 55,000 barge shipments and 4,000 ocean-going vessels annually. Over 60% of U.S. soybean exports are shipped through the New Orleans Port Region (U.S. Department of Agriculture, 2017). If an avulsion were to occur, the Mississippi River beyond Old River would become impassible due to draft limitations. This would impact the shipment of several agricultural commodities, including soybeans. Cargo vessels used for overseas bulk soybean shipments would not be able to reach ports as far north as Baton Rouge. Additionally, the possible disruption of river commerce beyond the ORCS would force producers to consider shipping soybeans using more costly alternative modes of transportation. Assuming the Mississippi River to be the most cost-efficient method of transporting soybeans, use of other modes of transportation to meet global demands would increase total transportation costs.

The Mississippi River has one of the largest drainage basins in the world, serving as an outlet for approximately 41% of the contiguous United States (U.S. Army Corps of Engineers, 2019). The ORCS maintains the distribution of water between the Mississippi and Atchafalaya Rivers (see Figure 1), where 1.2 million square miles of drainage narrow into an area approximately 40 miles wide (Barnett, 2017). The ORCS distributes roughly 70% of the flow down the Mississippi River and 30% down the Atchafalaya River (Kazmann and Johnson, 1980). Floods in 1927 and 1973 highlighted the need for the existing ORCS and its associated structures. However, while the Army Corps of Engineers has thus far controlled the flow of the river at a 70–30 split, some maintain that a shift in the course of the river is inevitable (Barnett, 2017).

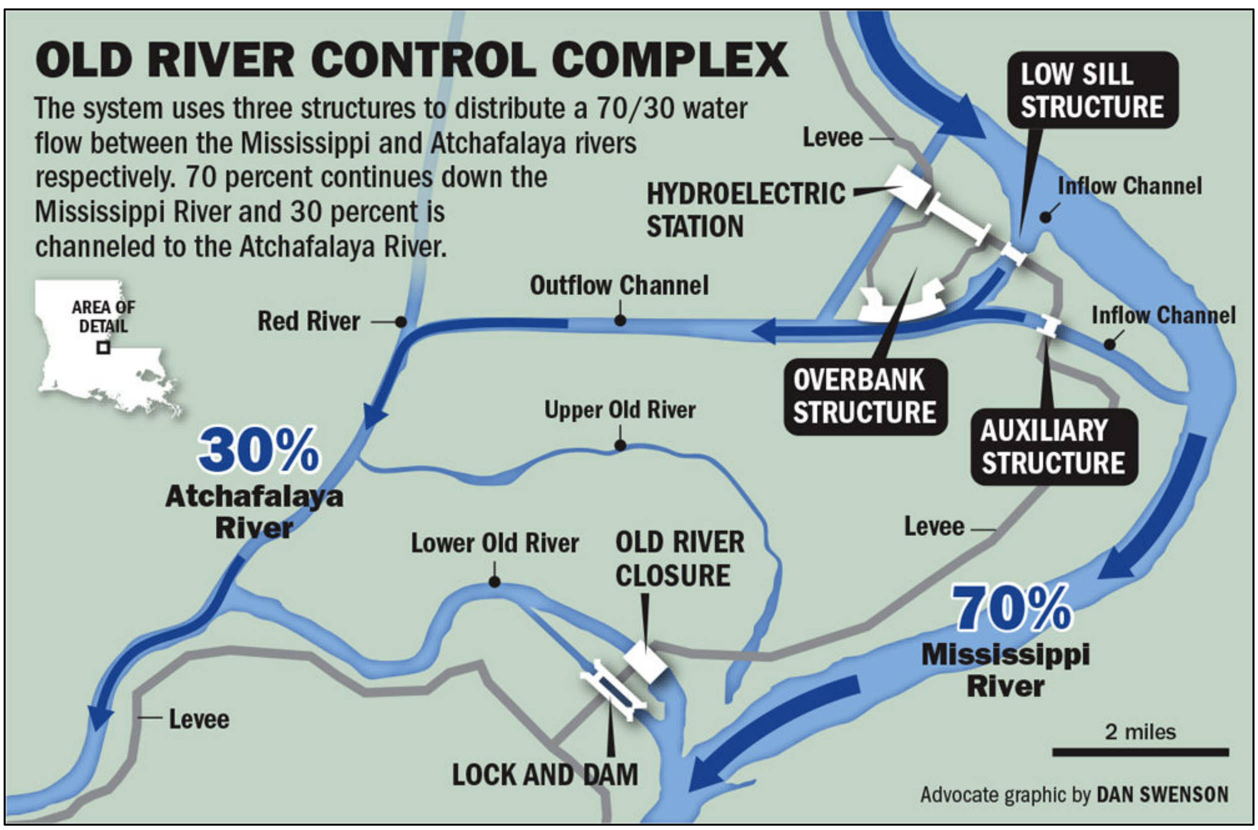

Figure 1. Map of Old River Control Complex
Source: Hardy (2018).

Theory suggests that the occurrence of a natural disaster will cause environmental, economic, and social impacts on the infrastructure of the affected area (Neal, 2014). The occurrence of a natural event—such as heavy rainfall, massive snowmelt in the Midwest region, or an intensive storm surge pushed up a flood-stage river—would increase the flow of water in the Mississippi River. This increase in flow would exceed the allotted discharge capacity of the ORCS, causing it to fail. As a result, river discharges of both the Mississippi and Atchafalaya Rivers would interchange, causing most of the water to enter the Atchafalaya River indefinitely. Flood damages, saltwater intrusion, the highway and transportation sector, and natural gas supply would be impacted. The disorder of the highway and transportation sector would directly affect soybean transportation infrastructure due to the Mississippi River becoming impassible below Old River.

A worst-case scenario assumes that substantially more water will be diverted to the new route to the Gulf. As a result, transport by barge to ports along the lower Mississippi would become increasingly difficult and eventually impossible due to lowered channel depths and vessel draft restrictions. Because the flow of water in the lower Mississippi channel would be minimal, the backflow of water from the Gulf of Mexico will be pushed up-river, allowing ocean-going vessels to access ports along the New Orleans Port Region. In the immediate aftermath of an avulsion, alternative transportation modes would be needed to meet the demands of foreign consumers. When transporting soybeans abroad, railroads occupy the second-highest modal shares after transport by barge (Denicoff, Prater, and Bahizi, 2014). Much uncertainty exists as to what the intermediate or long-term infrastructure would look like. Could the existing route be recaptured? Would the environmental lobby allow new ports and facilities on the "new" lower Mississippi River to be built? Could a slack-water estuary (system of lakes using locks and dams) be built between Baton Rouge and New Orleans to allow for barge travel along the current route?

The three alternative export regions in the United States that service soybean shipments (PNW, Atlantic, and Great Lakes) have limited capacities and specialize mainly in containerized rather than bulk shipping. Given that the ability to transport soybeans to the New Orleans Port Region—which is known for bulk shipping and exports approximately 60% of soybeans abroad—would be questionable after an avulsion, it is important to consider the shipping capacities of other ports of export and their ability to accommodate larger export quantities. The importance of and lack of research in this area encourage a closer look at the potential economic implications of an avulsion on U.S. soybean trade.

An avulsion of the Mississippi River due to the failure of the ORCS could have several economic and physical consequences. Based on previous research, a generalized hypothesis can be made regarding how U.S. soybean trade will be affected. Although this study seeks to examine the impact of an avulsion on soybean transport, the results have implications for the transportation and export of a variety of agricultural and nonagricultural commodities.

Review of Literature

Commodity disruptions as a result of compromised transportation infrastructure could occur as a result of a flood or any type of natural disaster; therefore, it is important to understand the economic impact of these disruptions. Pant et al. (2011) modeled atypical activity at ports of export through simulations capable of quantifying the number of commodities at every operating point. They used a multi-regional inoperability input–output model and multiregional extensions along with a simulation model to provide estimates of incoming and outgoing commodities through the ports.

A similar study conducted by Pant, Barker, and Landers (2014) examined the economic losses from disruptions in imports and exports of commodities on ports of export and waterways. The increase in containerized freight transport allows for the investigation of disruptions in transporting containerized freight caused by extreme weather conditions or other circumstances. They used a risk-based extension to the economic input–output model that describes the interdependent relationship among industry and infrastructure sectors in meeting final demand as well as a multiregional, multi-industry interdependency model and a simple discrete-event simulation model for commodity arrivals and departures at several docks.

Of particular relevance to this analysis, various models have been utilized to determine the impact of waterway disruptions on the movement and export of U.S. grains and oilseeds. Fuller and Grant (1993) used a least-cost network flow model to examine the impact of lock delay on transportation efficiency. Fuller, Fellin, and Eriksen (2000) used a spatial equilibrium model to examine the importance of the Panama Canal to U.S. corn and soybean exports. Their analysis examined the impact of increased Panama Canal tolls on U.S. exports and the impact of a disruption via complete closure of the canal. Fellin et al. (2008) used a spatial model to examine the impact of a catastrophic event on Mississippi River Lock and Dam 27 for the movement of agricultural commodities. They determined the value of the upper Mississippi and Illinois Rivers for grain transport to be between \$229 million and \$806 million. Yu, English, and Menard (2016) also used a spatial equilibrium model to examine the impact of closures on the upper Mississippi and Illinois Rivers. However, their analysis considered disruptions due to lock closures at Mississippi River Lock 25 and Illinois River La Grange Lock. Yu, English, and Menard found that the closure of Lock 25 for the marketing year resulted in a \$747 million loss of economic surplus to the U.S. corn and soybean sectors; the closure of the La Grange Lock for the marketing year resulted in a \$549 million loss.

Güler, Johnson, and Cooper (2012) analyzed the impact of a partial or full disruption on the transportation system between coalmines and coal-dependent power plants located in the Ohio River Basin. Using a minimum cost flow model, the authors were able to minimize total system transportation cost of coal while meeting service and capability constraints.

Kruse et al. (2018) analyzed the economic impact of the Gulf Intercoastal Waterway (GIW) on Texas, Louisiana, Mississippi, Alabama, and Florida using the IMPLAN model, a modeling tool that enhances the general input–output model approach. The authors also examined the impact of an abrupt closure of the GIW, which would force shipments usually transported by barge to shift to rail and truck transport.

Oztanriseven and Nachtmann (2017) used a simulation-based approach to examine the economic impacts of a navigable inland waterway's disruption response, which includes responses based on commodity type. Their methodology measured the total economic loss during a disruption based on shippers' decisions to wait for the inland waterways to reopen or transfer cargo to an alternative mode of transportation and considered short-, medium-, and long-term scenarios.

The demand for agriculture commodities has a significant influence on the economy; therefore, it is also important to look at supply chain logistics of those commodities. The rapid growth of soybean production and exports places a huge burden on the transportation sector to fulfill growing demands. Once the flow of shipment of commodities, such as soybeans, is disrupted, a producer must find ways to reroute their product for shipment and export. Bai et al. (2017) developed a modeling framework and detailed calculation procedure to analyze total transportation costs for containerized soybean exports. The methodology assessed the cost of containerized shipments from a specific point in the United States to a destination point to identify least-cost transportation options. Lopes, Lima, and Ferreira (2016) conducted a similar transportation cost study using a transportation network model to minimize costs among alternative soybean export routes in Brazil.

Reis and Leal (2015) proposed a mathematical model that allows an individual soybean shipper to plan the logistics for a soybean supply chain. Soybean supply in Brazil is much lower than demand, so suppliers must determine how much soy they will bring to the market. There is also a shortage of rail transport due to travel by roadway being a cheaper alternative. Models used to plan for the food supply chains were strategic, tactical, and operational. The mathematical model used for this study was a linear programming model set to maximize profit with continuous and nonnegative variables.

Gohari et al. (2018) used a theoretical intermodal network to identify the shortest path and other modes of transport for containers being shipped from an origin to destination point based on minimal time, distance, cost, and carbon dioxide emission objectives. Trade-offs associated with different transportation modes were also identified.

The literature examined provides insight on topics relevant to this study; however, essential questions remain unanswered. First, published studies that focus on waterway disruption through the closure of waterways or dams find that the absence of barge transport increases total transportation costs. However, after a thorough review, no literature was found to assess the economic implications of the potential impassibility of the Mississippi below Old River, an area that distributes over 60% of U.S. agricultural export volumes. In addition, soybean logistic studies examine the most cost-effective routes when all modes of transportation are available, but there is lack of research that measures cost-efficient routes from an origin to a destination port in a foreign country given the impassibility of the Mississippi River as well as how these costs change as a result of an avulsion. This research seeks to fill these gaps.

Estimation Methods

Based on the review of literature and the scope of this research, it was determined that a network optimization model would yield dependable estimates of the economic impact of U.S. soybean trade. The network optimization model used to conduct the analysis is the minimum cost flow model, a model that can combine and efficiently solve maximum flow, shortest path, and transportation applications, all of which are needed when determining a plan for transporting commodities from their supplier to storage facilities and then to consumers (Hillier and Lieberman, 2015).

Using a minimum cost flow model requires supply, demand, transshipment, and constraints. Incorporating the transportation costs of truck, rail, and barge, production region supply and the demand of the destination country, as well as the capacities of port of export regions into the model, will allow us to determine the least-cost route combinations while minimizing total overall cost to transport product to a final destination.

Many soybean production sites exist at the county level. To simplify, it is assumed that the supply node will be represented best by a location that is equally distant from barge and rail transportation (Bai et al., 2017). Five production regions were included to represent annual soybean production. States that produced over 100,000,000 bushels annually were selected and divided into regions based on Bureau of Economic Analysis business areas.

The mathematical model used for this analysis is adapted from Lopes, Lima, and Ferreira (2016) and is presented below in equations (1)–(10). The objective function seeks to minimize the total transportation cost of shipping soybeans through current routes in a pre-avulsion scenario and alternative routes and modes in a post-avulsion scenario to meet foreign demand:

(1) $$\text{Minimize } Z = \Sigma_{i=1}^{n}\Sigma_{j=1}^{m}\Sigma_{k=1}^{o}\,(c_{ij} + c_{jk})x_{ijk}$$

subject to the following constraints and transportation costs:

(2) (a) production region supply: $\Sigma_{i=1}^{n} x_{ijk} \leq P_i \; for \; i = 1, \dots, n;$

(3) (b) destination demand: $\Sigma_{k=1}^{o} x_{ijk} = D_k \; for \; k = 1, \dots, m;$

(4) (c) transshipment constraints: $\Sigma_{j=1}^{m} x_{ij} - \Sigma_{j=1}^{m} x_{jk} = 0;$

(5) (d) port capacity: $\Sigma_{j=1}^{n} x_{ijk} \leq T_i \; for \; j = 1, \dots, m;$

(6) (e) transportation costs: $c_{ij} = c_t + c_r + c_b + c_u,$

where c_t represents truck transportation cost in dollars per metric ton ($/MT); c_r represents rail transportation cost in $/MT; c_b represents barge transportation cost in $/MT; and c_u represents modal change unitary cost in $/MT when multiple modes are used.

Considering that for equation (6):

(7) $$u \geq 0$$

and

(8) $$c_u \geq u \cdot c_{uf},$$

where u represents the number of modal changes for x_{ij}; and c_{uf} represents modal change cost in \$/MT.

For c_{ij}:

(9) $$c_{jk} = c_s,$$

where c_s represents ocean transportation cost in \$/MT.

(10) (f) nonnegative conditions: $x_{ijk} \leq P_i \; for \; i = 1, \dots, m; j = 1, \dots, n; k = 1,$

where m indicates the number of exporting port regions; n indicates the number of soybean production regions; o indicates the number of importing ports; T_j represents port j's capacity to export soybeans; P_i represents the quantity of soybeans produced in metric tons in each region i; c_{ij} represents the transportation cost of shipping soybeans from production region i to exporting port region j; c_{jk} represents the transportation cost of shipping soybeans from exporting port j to importing port k; x_{ijk} represents the volume of soybeans shipped from production region i to exporting port j and exporting port j to importing port k; and Z represents the total transportation cost of soybean shipment.

The economic impact of an avulsion on soybean trade flows is estimated as follows: First, we identify the pre- and post-avulsion supply chains. This includes original and alternative routes, intermodal facility locations, and port of export regions. The next step is to obtain truck, rail, barge, and ocean transportation costs for domestic shipments from producer to final destination. The final step is to calculate total shipment costs for original shipment routes for a pre-avulsion scenario and total shipment costs using alternative routes and modes of transportation for a post-avulsion scenario.

In addition, based on revealed preferences, it is assumed that transporting soybeans downstream via barge along the Mississippi River for export through New Orleans is the most cost-efficient mode of transportation for soybean producers. If there were a cheaper alternative for shipping soybeans, this alternative would already be used. Therefore, we assume that the costs associated with alternative modes of transportation would increase transportation costs of soybean exports. This would result in a negative trade-off due to the costs associated with increasing infrastructure in competing port regions (PNW, Atlantic, and Great Lakes), exceeding costs that would be saved if the Mississippi remained accessible to barge transportation. Another assumption is that competing port regions cannot increase infrastructure in the short term. Thus, current port capacities will be used, and an avulsion of the Mississippi at Old River would disrupt barge travel to the Mississippi Gulf. Additionally, it is assumed that approximately 48% of soybeans produced are exported to other countries and approximately 79% of soybeans exported are shipped to East Asia (Shanghai), EU-27, the United Kingdom, and South Asia (Rotterdam), and Mexico

(Veracruz). Because supply and demand in a minimum cost flow model must equal one another, the percentage of soybeans exported to the previously mentioned regions would represent the flow in the model.

For simplicity, we do not include local transportation from the harvest site to intermodal facilities or from the port of import to the final destination point. Additionally, we assume that rail and highway infrastructure is sufficient, and no additional costs are included to address capacity constraints of substituting rail hopper cars and trucking for barges. Based on the mathematical model presented, we used Microsoft Office Excel Solver to run the optimization scenarios considered.

Data and Scenario Analysis

Data for this research were obtained from the USDA Agricultural Marketing Service (AMS), which provides soybean movement data and barge rates. Modal transportation costs of truck and ocean rates were obtained from AMS *Grain Truck and Ocean Advisory* reports. Since ocean rates for certain port of export regions were not readily available, we used rates from multiple reports to determine the average mile per metric ton rates of bulk grain exports from reported port of export regions to the same destination. Ocean and truck routes were calculated using Netpas software and PC*Miler Copilot software. We also used the Surface Transportation Board (STB) Public Waybill Sample to analyze soybean rail movements from various Bureau of Economic Analysis business areas to port of export destinations. Rail rates for those movements were extracted from the Waybill Sample. Selected rail routes were extracted from the Tariff and Rail Rates for Unit and Shuttle Train Shipment dataset used in the *Grain Transportation Report*, a weekly AMS publication, and compared to Waybill Sample rail rates so that rates were within reasonable ranges. Soybean production data, measured in bushels, were obtained from the USDA National Agricultural Statistics Service (NASS) Quick Stats Database. Soybean export data were obtained from two databases—the Global Agricultural Trade System and Production, Distribution, and Supply—both of which are provided by the USDA Foreign Agricultural Service (FAS). Class I railroad network data and intermodal facility data were obtained from the U.S, Department of Transportation Bureau of Transportation Statistics (BTS).

A network optimization model was utilized to estimate the economic impact of U.S. soybean trade following an avulsion of the Mississippi River. Because this analysis assumes the most current logical and least-cost routes, routes were generated based on general assumptions of current shipping and future routes to ports of export assuming the impassibility of the Mississippi below Old River and the elimination of barge travel to the New Orleans Gulf Port Region. Production regions selected for the analysis are in the Midwest region of the United States, which produces over 80% of U.S. soybeans and is along the lower Mississippi River corridor.[1] Production regions are Region 1 (S1) (Illinois, Indiana, and Ohio), Region 2 (S2) (Minnesota, Wisconsin, and North

[1] In 2017 the top soybean-producing states were Illinois, Iowa, Minnesota, Indiana, Nebraska, Missouri, Ohio, Mississippi, Arkansas, North Dakota, South Dakota, Tennessee, and Kentucky. These states, except for Tennessee, all produced over 100 billion bushels of soybeans, with Iowa and Illinois both producing well over 500 billion bushels (U.S. Department of Agriculture, 2019).

and South Dakota), Region 3 (S3) (Missouri and Iowa), Region 4 (S4) (Nebraska, South Dakota, and Iowa), and Region 5 (S5) (Arkansas, Mississippi, and Kentucky). St. Louis (P1') is an inland port and will act as a route alternative for exports. Port of export regions are the New Orleans Gulf (Gulf), PNW, Atlantic, and the Great Lakes. We used ArcMap to identify truck, rail, and port intermodal facilities in each production region.

Approximately 89% of soybeans destined for export are shipped to a local elevator, while 11% are shipped directly from the harvest site (Informa Economics, 2016). Once soybeans arrive at the local elevator, they are transported via truck or rail to a nearby intermodal facility within a 50-mile radius for transport to a port of export destination. For simplicity, the analysis will consider transportation costs of shipping soybeans from an intermodal facility located in each production region to the port of export (transshipment point) and from the transshipment point to the port of import (destination). Figure 2 presents a map of the production regions, intermodal facility locations, and port of export regions.

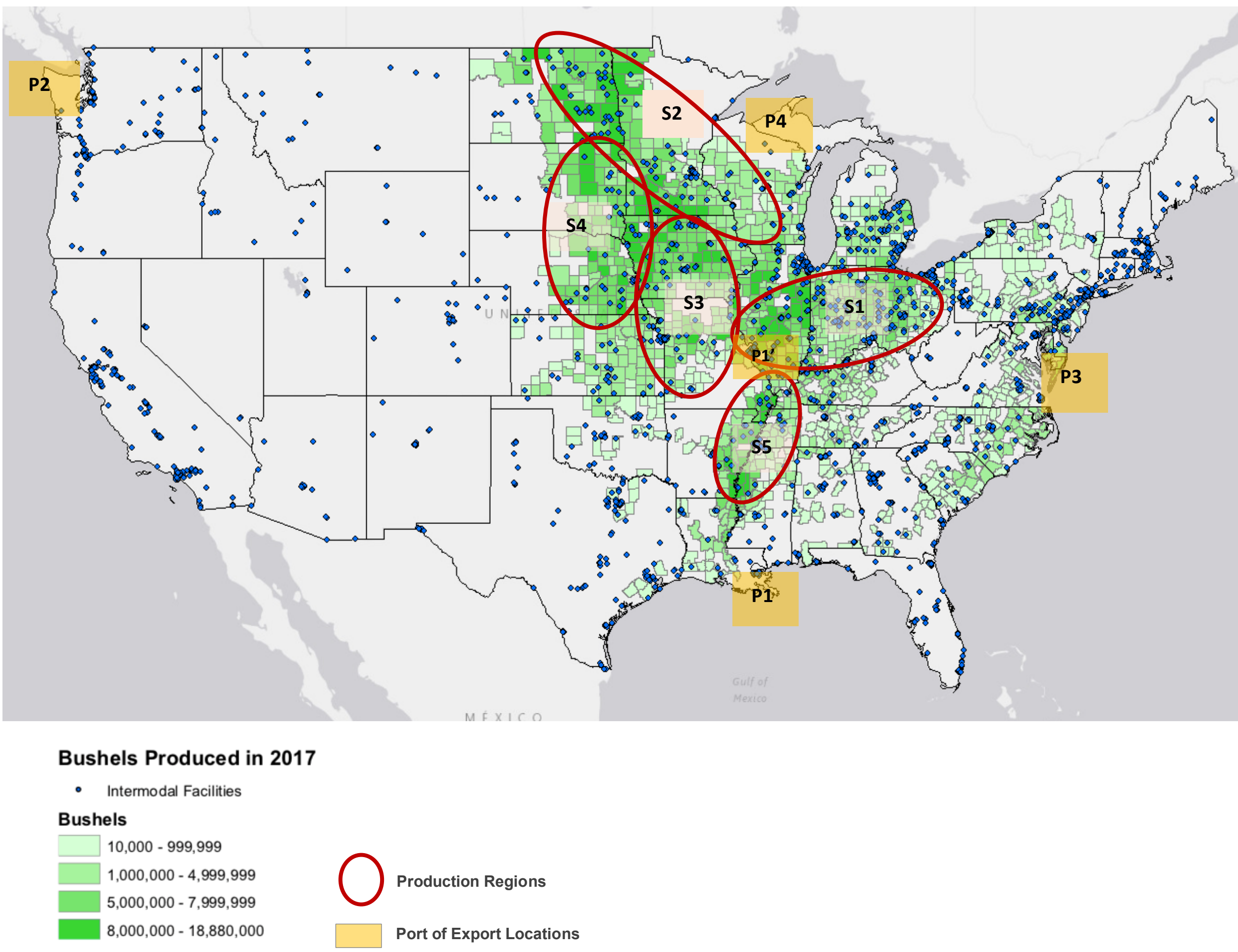

Figure 2. 2017 U.S. Soybean Production by County, Production Regions, Intermodal Facility Locations, and Port of Export Regions
Source: USDA National Agricultural Statistics Service and Bureau of Transportation Statistics Service.

Because the United States is a net soybean exporter, soybean exports for each region are based on the demands of the selected regions (Shanghai, Rotterdam, and Veracruz), all top importers of U.S. soybeans. To estimate the quantity of soybeans exported to these regions, we multiplied the percentage of soybeans exported to the world by the amount of soybeans produced in each production region state. Once we had estimated the export supply to the world, we multiplied soybean production by the export percentages to the regions. To eliminate the possibility of counting states represented in multiple production regions, we divided the export percentage of each state by the number of times a state appeared in each region. For example, Iowa is represented in two production regions; half of its total export production was distributed to each of the two regions in which it appeared.

For this analysis, two scenarios were used to show the differences in total transportation costs before and after an avulsion of the Mississippi River at Old River: a pre-avulsion and a post-avulsion scenario. To ensure parallelism in the results, each scenario used the same supply, demand, costs, and transshipment constraints. The pre-avulsion scenario attempts to replicate the current estimated transportation costs using transshipment constraints prior to an avulsion as well as all available transportation modes from the production regions to the transshipment regions and from the transshipment regions to the final port of import. As noted previously, the model does not include transportation costs from the harvest site to the local elevator to the intermodal facility. Additionally, routes from transshipment point to the final port of import will remain the same in both scenarios. In the pre-avulsion scenario, soybeans can be shipped via barge, rail, or truck to port of export locations. The post-avulsion scenario represents the transportation costs of shipping soybeans after an avulsion, removing the possibility of barge travel below the ORCS.

Table 2 presents capacity constraints for origins, transshipment locations, and destinations. Transshipment capacities were estimated using 2017 soybean exports to the selected regions. The difference in supply and demand capacity of soybeans resulted in an unbalanced optimization problem. To change the problem to a balanced problem, an additional production region (Dummy 1) was added to the model. The inclusion of a dummy variable allowed the production region supply to remain less than or equal to the considered supply constraint and the destination demand remains equal to considered demand constraint resulting in a feasible solution. Another way to solve this problem was to set the production region supply equal to the considered supply constraint and the destination demands remain less than or equal to the considered demand constraint. Production areas not included in the primary regions are represented by a dummy variable. The inclusion of the dummy variable requires its costs to equal 0. These costs will not be 0; therefore, the final transportation cost to export soybeans will be higher than the costs calculated in the optimization model.

Considering the finite export capacities of individual ports, this analysis uses port of export regions (unlike other optimization models). Typically, the USDA aggregates soybean exported within their respective port of export regions to represent total export percentages for that port of export region. For example, soybeans shipped through the New Orleans Gulf Port Region represent approximately 60% of U.S. soybeans exported, whereas soybeans shipped through the PNW region represent approximately 25% of soybeans exported (U.S. Department of Agriculture, 2017).

Due to variation in rail rates with identical routes, we used the average rail cost to represent the rail cost to port of export regions with multiple representative ports.

Simulation Results

Results of the optimization simulations are presented in Tables 3–5. Table 3 presents the per unit inland transportation costs for the pre- and post-avulsion scenarios. Inland transportation costs represent the total transportation cost of shipping soybeans from an intermodal facility within a production region to a port of export location and includes unitary modal change handling costs. The average inland transportation cost for all possible routes is $34.94/MT or $0.95/bushel, pre-avulsion. These costs increase to $49.63/MT or $1.35/bushel, an overall average of 42.06%, post-avulsion. However, given that the analysis considers the disruption of barge transportation in the lower Mississippi River and only those routes previously utilizing the lower Mississippi River for barge transportation, the three routes experiencing transportation cost increases are between the Gulf and Regions 1, 3, and 5. Inland transportation costs for shipping to the Gulf from Regions 1, 3, and 5 increased by 113.85%, 67.61%, and 289.65%, respectively.

The pre-avulsion scenario, which represents the pre-avulsion status quo, shows a transportation cost of $2.401 billion. When modal change costs of $0.228 billion are added, the final total transportation cost in the pre-avulsion scenario increases to $2.628 billion.[2] Shipments are considered to change modes when being loaded and unloaded for transition between transportation modes. For example, a total of three modal changes are assumed for a route leaving a local elevator destined for an intermodal facility in Region 1 to the Gulf and from the Gulf to the final destination. These changes are determined by the loading of soybeans onto shuttle rail cars or barge destined for the Gulf and the unloading and reloading of soybeans onto an ocean-going vessel to a region. In the pre-avulsion scenario, 68.87% of total shipments destined for all regions were transported to the Gulf via barge, while 30.25% were sent to the PNW via rail. All other shipments, less than 1%, were shipped by truck to the Great Lakes or shipped via the alternate dummy route to the Atlantic port region. This is most likely due to the high modal transportation costs; however, the low capacity of these ports for bulk agricultural commodities may have played a factor as well.[3] Regardless of the reason for the low quantity of shipments to the Atlantic and Great Lakes regions, this is logical given that the availability of barge travel along of the Mississippi River extends from Minneapolis–St. Paul down the Mississippi River to the Gulf of Mexico.

The least-cost alternative in the post-avulsion scenario is a transportation cost of $3.118 billion, a 29.88% increase. As discussed in the hypothesis, this result is consistent with expectations since

[2] Modal change costs are estimated to be approximately $0.05 per bushel per mode change.

[3] To ensure the existence of routes for each production region and port export region route, truck rates were substituted in cases when rail transportation costs were not available. The truck mile-per-metric ton rate obtained from the Grain Truck and Ocean Rate Advisory (U.S. Department of Agriculture, 2018) was multiplied by the average mileage of the intermodal facility geographically located in the center of Bureau of Economic Analysis business areas to the designated port of export region.

Table 2. Capacity Constraints for Origins, Transshipment Locations, and Final Destinations

Origins	Supply (MT)	Trans-shipment Locations	Port Capacity (MT)	Destinations	Demand (MT)
Region 1 OH, IN, IL (S1)	12,749,104	Gulf Region (P1)	30,219,834	Shanghai (C1)	35,294,766
Region 2 MN, SD, ND, WI (S2)	9,546,752	PNW Region (P2)	14,957,354	Rotterdam (C2)	6,471,701
Region 3 MO, IA (S3)	6,469,264	Atlantic Region (P3)	1,412,447	Veracruz (C3)	2,106,827
Region 4 IA, SD, NE (S4)	8,200,456	Great Lakes Region (P4)	704,881		
Region 5 MS, AR, KY (S5)	4,452,601				
Total	41,418,177			Total	43,873,293

Note: Capacities were estimated using USDA AMS GATS Database.

Table 3. Inland Transportation Cost Comparison

	Pre-Avulsion		Post-Avulsion		
Route	$/MT	$/bu	$/MT	$/bu	% Change
Region 1 to Gulf	20.98	0.57	44.87	1.22	113.87
Region 2 to Gulf	29.89	0.81	–	–	–
Region 2 to PNW	61.10	1.66	61.10	1.66	0.00
Region 2 to Great Lakes	33.21	0.90	33.21	0.90	0.00
Region 3 to Gulf	24.85	0.68	41.65	1.13	67.61
Region 4 to Gulf	–	–	54.10	1.47	–
Region 4 to PNW	61.42	1.67	61.42	1.67	0.00
Region 5 to Gulf	13.10	0.36	51.06	1.39	289.77
Average	34.94	0.95	49.63	1.35	42.06

Note: Hyphens in the pre- and post-avulsion columns indicate that soybeans were not shipped using that route. As a result, the percentage change for those routes could not be calculated.

Table 4. Port of Export and Port of Import Shipment Comparison

	Pre-Avulsion Scenario			Post-Avulsion Scenario			
Port of Export Route	**Soybeans (MT)**	**Cost ($/MT)**	**Total Cost**	**Soybeans (MT)**	**Cost ($/MT)**	**Total Cost**	**% Change in Shipment**
Region 1 to Gulf	12,749,104*	$20.98	$197,228,638	12,749,104**	$44.87	$501,766,486	0.00%
Region 2 to Gulf	6,548,865*	$29.89	$159,654,779	–	–	–	–
Region 2 to PNW	2,617,234**	$61.10	$145,478,951	8,841,871**	$61.10	$491,475,400	237.83%
Region 2 to Great Lakes	380,653***	$33.21	$11,241,825	704,881***	$33.21	$20,817,251	85.18%
Region 3 to Gulf	6,469,264*	$24.85	$125,089,688	6,469,264**	$41.65	$233,766,855	0.00%
Region 4 to Gulf	–	–	–	4,538,639**	$54.10	$220,532,479	–
Region 4 to PNW	8,200,456**	$61.42	$458,446,492	3,661,817**	$61.42	$204,713,868	−55.35%
Region 5 to Gulf	4,452,601*	$13.10	$33,808,599	4,452,601**	$51.06	$202,815,976	0.00%
Port of Import Route	**Soybeans (MT)**	**Cost ($/MT)**	**Total Cost**	**Soybeans (MT)**	**Cost ($/MT)**	**Total Cost**	**% Change in Shipment**
Gulf to Shanghai	22,027,139	$38.37	$845,137,269	20,016,913	$38.37	$768,008,926	−9.13%
PNW to Shanghai	13,267,627	$20.37	$270,301,364	14,953,625	$20.37	$304,650,198	12.71%
Great Lakes to Shanghai	–	–	–	324,228	$47.11	$15,274,919	–
Gulf to Rotterdam	6,471,701	$15.97	$103,320,706	6,471,701	$15.97	$103,320,706	0.00%
Gulf to Veracruz	1,720,994	$13.25	$22,803,170	1,720,994	$13.25	$22,803,171	0.00%
PNW to Veracruz	3,729	$86.78	$323,591	3,729	$86.78	$323,591	0.00%
Atlantic to Veracruz	380,653	$73.23	$27,877,075	380,653	$73.23	$27,877,075	0.00%
Great Lakes to Veracruz	1,451	$28.74	$41,706	1,451	$28.74	$41,706	0.00%
Overall Cost							**% Change in Cost**
Shipping Cost		$2,400,753,860			$3,118,188,606		29.88%
Modal Change Cost		$227,579,230			$226,983,563		−0.26%
Total Shipping Cost		$2,628,333,090			$3,345,172,169		27.27%

Note: Hyphens in the pre- and post-avulsion columns indicate that soybeans were not shipped using that route. As a result, the percentage change for those routes could not be calculated. Asterisks in the table represent modes used before and after avulsion. They are identified as follows: "Barge" *, "Rail" **, and "Truck" ***. Shipments destined for a Port of Import are transported on an ocean vessel. The cost of mode changes is estimated to be $1.84 per metric ton of soybeans which can range between two to four changes per route depending on modes used. Mode changes are assumed to occur when shipments are transported from a local elevator by rail or truck and unloaded at an intermodal facility; reloaded and transported from the intermodal facility by rail, barge, or both and unloaded at a port of export; and finally reloaded onto an ocean vessel for transport to a port of import. For example, a total of three modal changes are assumed for a route leaving a local elevator destined for an intermodal facility in Production Region 1 to the New Orleans Gulf Port Region and from port region to the final destination.

Table 5. Pre- and Post-Avulsion Transportation Costs for Alternative Routes ($/MT)

	Gulf			PNW		Great Lakes	
Pre-Avulsion Scenario	**Shanghai**	**Rotterdam**	**Veracruz**	**Shanghai**	**Veracruz**	**Shanghai**	**Veracruz**
Region 1 via Gulf to:	$59.35	$36.95	$34.23				
Region 2 via Gulf to:	$68.26	$45.86	$43.14				
Region 3 via Gulf to:	$63.22	$40.82	$38.10				
Region 4 via Gulf to:	–	–	–				
Region 5 via Gulf to:	$51.47	$29.07	$26.35				
Region 2 via PNW to:				$81.47	$147.88		
Region 4 via PNW to:				$81.79	$148.20		
Region 2 via Great Lakes to:						–	$61.95

	Gulf			PNW		Great Lakes	
Post-Avulsion Scenario	**Shanghai**	**Rotterdam**	**Veracruz**	**Shanghai**	**Veracruz**	**Shanghai**	**Veracruz**
Region 1 via Gulf to:	$83.24	$60.84	$58.12				
Region 2 via Gulf to:	–	–	–				
Region 3 via Gulf to:	$80.02	$57.62	$54.90				
Region 4 via Gulf to:	$92.47	$70.07	$67.35				
Region 5 via Gulf to:	$89.43	$67.03	$64.31				
Region 2 via PNW to:				$81.47	$147.88		
Region 4 via PNW to:				$81.79	$148.20		
Region 2 via Great Lakes to:						$80.32	$61.95

	Gulf			PNW		Great Lakes	
Percentage Change	**Shanghai**	**Rotterdam**	**Veracruz**	**Shanghai**	**Veracruz**	**Shanghai**	**Veracruz**
Region 1 via Gulf to:	40.25%	64.65%	69.79%				
Region 2 via Gulf to:	–	–	–				
Region 3 via Gulf to:	26.57%	41.16%	44.09%				
Region 4 via Gulf to:	–	–	–				
Region 5 via Gulf to:	73.75%	130.58%	144.06%				
Region 2 via PNW to:				0.00%	0.00%		
Region 4 via PNW to:				0.00%	0.00%		
Region 2 via Great Lakes to:						–	0.00%

Source: Author Calculations based on data from Table 3.

the optimized route in the pre-avulsion scenario utilized barge travel for most of the inland shipments to ports of export. The modal change cost of shipping soybeans decreased 0.26% in the post-avulsion scenario. When modal change costs of $0.227 billion are added, the total transportation cost increases by 27.27% to $3.345 billion.

Although the inland transportation cost of soybeans for individual routes increased significantly in the post-avulsion scenario, shipments from Region 1, 3, and 5 to the Gulf remain unchanged. An additional shipment route, Region 4 to the Gulf, is used in the post-avulsion scenario but was not used in the pre-avulsion scenario. Conversely, the Region 2 route to the Gulf, which was used in the pre-avulsion scenario, was not utilized in the post-avulsion scenario.

Soybean shipments to Shanghai and Veracruz from the Great Lakes are minimal in both scenarios when compared to shipments from the Gulf and PNW. Similarly, just a small fraction of total soybean exports was shipped from the Atlantic region. As mentioned previously, this could be due to the limited capacity of these port facilities and alternative cost estimates for those routes.

When ocean costs are added to the inland costs, the total transportation cost of exporting soybeans from Region 1 via the Gulf to Shanghai, Rotterdam, and Veracruz increases to $83.24/MT, $60.84/MT, and $58.12/MT, respectively (Table 5), due to a disruption caused by an avulsion at the ORCS, or a 40.25%, 64.65%, and 64.79% increase in total transportation costs, respectively. Similar increases are seen in transportation costs through the Gulf for the other production regions. Although the transportation costs for exports through PNW and the Great Lakes do not increase, these routes become more advantageous in relative terms given the cost increases of the Gulf routes.

In addition to comparing the total transportation costs per metric ton and bushel, we also estimated the cost, insurance, and freight (CIF) price of exported soybeans from an intermodal facility to a port of export region and from a port of export region to the final destination. For simplicity, these results are presented for delivery to Shanghai. To estimate the CIF prices, we calculated the 2017 average farm price received for states represented in each production region. Since this price is reported as a per bushel cost, we converted the cost to a metric ton cost. For this analysis, the farm price will serve as the free-on-board (FOB) intermodal facility price (USDA-NASS). The CIF prices for Shanghai is total transportation costs, which include the inland and ocean transportation cost, added to the FOB price. Table 6 presents the CIF price for soybeans delivered to Shanghai. An avulsion would result in a 5.79%, 4.23%, and 9.28% increase in CIF Shanghai price for soybeans shipped from Regions 1, 3, and 5, respectively, via rail to the Gulf.

Table 6. Calculated CIF Price, China

	2017 FOB	Pre-Avulsion			Post-Avulsion			
Route	**Price Intermodal Facility ($)**	**Trans-portation Cost ($/MT)**	**CIF Price ($/MT)**	**CIF Price ($/bu)**	**Trans-portation Cost ($/MT)**	**CIF Price ($/MT)**	**CIF Price ($/bu)**	**Change in CIF Price (%)**
Region 1 to Gulf	353.11	59.35	412.46	11.23	83.24	436.35	11.86	5.79
Region 2 to Gulf	333.72	68.26*	401.98	10.94	–	–	–	–
Region 2 to PNW	333.72	81.47	415.19	11.30	81.47	415.19	11.30	0.00
Region 2 to Great Lakes	333.72	80.32	414.04	11.27	80.32	414.04	11.27	0.00
Region 3 to Gulf	334.00	63.22	397.22	10.81	80.01	414.01	11.27	4.23
Region 4 to Gulf	334.00	–	–	–	92.47*	426.47	11.61	–
Region 4 to PNW	334.00	81.79	415.79	11.32	81.79	415.79	11.32	0.00
Region 5 to Gulf	357.42	51.47	408.89	11.13	89.43	446.85	12.16	9.28

Note: Prices with asterisks represent the transportation costs of that route, although product may not have shipped in the previous or current scenario.

Research Implications

Results from the analyzed scenarios indicate that an avulsion would cause soybeans to shift from shipment to the Gulf by barge to rail, significantly increasing total transportation costs of soybean exports to East Asia (Shanghai); EU-27, the United Kingdom, and South Asia (Rotterdam); and Mexico (Veracruz). This result is logical given that barge travel along the Mississippi River to the Gulf is currently the most cost-efficient mode of transportation for inland soybean shipments; its disruption would result in increased transportation costs. However, given that this analysis looked at the economic impact of an avulsion on soybean exports, the increase in cost represents a lower bound. Logistical capacity constraints and increased demand for transport services as a result of an avulsion also contribute to this being the lower-bound cost.

The estimated increase in soybean transportation costs from the initial shock of an avulsion of the Mississippi River is $716.8 million (Table 4). If soybean exports to Shanghai, Rotterdam, and Veracruz remain constant, the cumulative increase in transportation costs of soybeans on an annual basis will exceed billions of dollars in the long run. It is important to note that this cost represents only the cost of shipping soybeans to the selected regions for 2017 and does not account for the remaining 21% of soybeans shipped to the rest of the world. Neither does it consider other agricultural commodities shipped from the New Orleans Gulf Port Region such as corn, wheat, rice, and other bulk commodities. If transportation costs of soybeans are assumed to increase, then the transportation costs of other agricultural commodities frequently shipped by barge are expected to increase as well.

In the optimization model, there were no capacity constraints on the number of barges, rail hopper cars, or trucks that could be used to ship soybeans to port of export regions. Given shipping time constraints, the number of available railcars, labor, and other factors such as market power, the increase in rail movement capacity to the New Orleans Gulf Port Region will likely cause rail costs to increase due to increased demand. Similarly, post-avulsion demand for barges would decrease and likely reduce the price for barges elsewhere. After an avulsion, the optimization model indicated that the New Orleans Gulf Port Region exported a combined 28.2 million metric tons—or approximately 1,036.5 million bushels—of soybeans to Shanghai, Rotterdam, and Veracruz. In the pre-avulsion scenario, all soybeans transported to the New Orleans Gulf Port Region were shipped via barge. Using this information, it can be assumed that shipments to the Gulf via rail in the post-avulsion scenario would have been sent via barge if that mode were available.

A 15-barge tow hauls approximately 787,000–855,000 bushels of soybeans, the equivalent of 219 rail hopper cars (Soy Transportation Coalition, 2019). The number of rail car hoppers that would be added to the current rail movement following an avulsion is 185,058–209,920 or, in terms of a 100-car unit train, 1,850–2,100 additional unit-train shipments of soybeans annually. The number of unit-train shipments to the PNW would also increase given the projected increase in the quantity of soybeans shipped to the PNW. This increase in rail shipments is not as large as the increase in shipments to New Orleans ports. The increase in unit-train shipments would also increase CO_2 emissions, result in possible delays of shipments due to congestion at loading facilities, and increase daily commute times of citizens at rail crossings as a result of increased unit-train traffic.

With respect to the post-avulsion increases in inland transportation costs, producers in Regions 1, 3 and 5 will experience higher per bushel transportation costs increases than producers in Regions 2 and 4 with the elimination of barge travel. Barge travel may not be eliminated completely and product from production Regions 1 and 3 may be able to travel as far south as Vicksburg or Natchez, Mississippi, by barge and from there shipped to the New Orleans Gulf by rail. Shipments from Region 5, which experiences the highest increase in intermodal facility costs, would most likely not have that option given their location. Because this is a worst-case scenario analysis, the combined transportation cost of barge and rail was assumed to exceed the rail transportation costs directly to the Gulf.

Results in the post-avulsion scenario also indicate that an avulsion would negatively impact U.S. soybean trade by reducing U.S. competitiveness in the world market. Production regions with increased inland transportation costs will also see increases in their respective CIF soybean prices of soybean exports to Shanghai. The CIF price is the price the selected regions will pay for soybeans imported from the United States. An increase in the CIF price will likely cause decreases in quantity demanded for U.S. soybeans on the world market, at constant FOB prices. However, a likely scenario would be that the U.S. FOB price would adjust downward to maintain a competitive CIF price on the world market relative to its export competitors, Brazil and Argentina.

Policy makers should consider this information as they evaluate potential investment in additional river maintenance to prevent an avulsion. Avulsion prevention practices include dredging, maintaining flood control structures, and preserving levee systems. To provide perspective on the dredging costs associated with maintaining the river, a project promoted by Mississippi River stakeholders will deepen the lower Mississippi River from 45 to 50 feet along the lower Mississippi shipping channel. The project will cover the final 256-mile stretch of river between Baton Rouge, Louisiana, and the Gulf of Mexico. Costs include planning, design, and research and are an estimated $237.7 million, or just under $929,000 per mile. This is likely a high estimate because it estimates dredging of an additional 3 feet while the river is usually dredged to at least 47 feet (Grainnet, 2019).

Conclusions

This research identified immediate alternative soybean export routes following a Mississippi River avulsion and compared the least-cost alternatives of shipping soybeans to port of export destinations and final demand destinations using pre- and post-avulsion scenarios. The results found are consistent with expectations and the literature. An avulsion would result in modal shifts from barge to rail.

This analysis provides a major building block from which a more extensive aggregate economic impact and cost–benefit analysis could be undertaken on two fronts. First, should an avulsion occur, society would be impacted in an abundance of areas too numerous to consider in a single analysis. Not only would transportation be impacted, but other issues—ranging from the availability of drinking water to industrial plant location—would arise. Even with respect to agricultural trade, many other export commodities, not to mention import commodities, would be affected. Second, with respect to a single agricultural export commodity such as soybeans, we narrow our focus to the immediate response. The intermediate and long-term responses to an avulsion should include increased capacity and price adjustments for other routes and modes as well as the potential development of alternative transportation infrastructure in the Gulf Region in response to the post-avulsion environment. These may include the development of the current lower Mississippi River as a slack-water estuary or the development of port infrastructure on the new lower Mississippi River.

This analysis makes several limiting assumptions, including holding alternative transportation costs (rail and truck) and domestic supply constant. It is important to note that holding transportation rates constant for other routes—such as the PNW, Great Lakes, and Atlantic regions—provides a lower bound for this analysis. The shift of product to these other routes or to other transportation modes to the Gulf will likely increase the respective transportation rates and further increase transportation costs beyond our calculations. Although domestic soybean supply was assumed to remain constant, longer-term impacts could experience a shift to alternative substitute crops, such as corn. However, given the export-dependence of the U.S. agricultural sector, those alternative commodities would likely experience the same transportation impacts as determined here. Future analyses could include the entire U.S. grains sector to better address this issue.

Relative to the $237.7 million dredging project between Baton Rouge and the Gulf of Mexico, the $716.8 million increase in the cost of transporting soybeans due to an avulsion warrants continued preventative maintenance of the lower Mississippi River. However, there are those who believe that an avulsion is an eventual certainty, regardless of human intervention (Barnett, 2017). Although continued upkeep and reinforcement of the ORCS and lower Mississippi River system is warranted, it would seem prudent for policy makers to consider options for investing in alternative transportation infrastructure. While this planning should consider options to guarantee low-cost access to the Gulf, forward-thinking leaders should also evaluate the vulnerability of the entire U.S. bulk-commodity transportation system. While an avulsion of the Mississippi River at the Old River Control Structure is certainly a possibility, it is not the only potential vulnerability either on the Mississippi River or throughout the entire U.S. transportation system. While the event considered in this analysis could certainly occur due to a natural disaster, this and other transportation infrastructure can fail for a variety of reasons, including terrorism and obsolescence. Some combination of appropriate maintenance and forward-thinking design is necessary to maintain U.S. competitiveness through an efficient transportation system. More detailed future analysis can contribute to this end.

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