Agricultural Export Gateways: Transportation Infrastructure Investment Modeling

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Domestic U.S. agriculture relies heavily upon an efficient multimodal transportation system in order to access international export markets. This is particularly true for grains (soybeans, wheat, corn), meat products and other high-value agriculture products. Increases in the efficiency of that transportation system lower the costs of production, increasing the competitiveness and expanding the market for agricultural products.
Yet for most of the publically provided transportation system (highway, ports, river navigation), investments haven't kept pace with needs, resulting in declining highway condition ratings, structurally deficit bridges and lock/dam system that requires significant investments.

There has been increased attention and focus on the importance of freight transportation at the local, regional and national level, including that connecting agricultural shippers. This has most recently materialized in the "Fixing America's Surface Transportation (FAST)" act, which dedicates an estimated $1.2 billion per year to improving the National Highway Freight Network (NHFN) to states through formula funding on projects that improve freight system efficiency. In addition, the act also created a discretionary competitive grant program with $4.5 billion over five years for regionally and nationally important freight projects, known as the "Fostering Advancements in Shipping and Transportation for the Long-term Achievement of National Efficiencies (FASTLANE)" program. These national and state resources are dedicated to address freight inefficiencies and improve freight system performance, including that connecting agriculture producers to export markets.

As individual states and different federal agencies begin developing candidate projects that are eligible for infrastructure investment dollars, there exist a need for a mechanism of evaluating how specific investments improve export competitiveness via mitigating bottlenecks or significantly lowering transportation costs. This research effort addresses that need by engaging with key stakeholder throughout the agricultural export supply chain and developing a model of major agricultural export corridors that allows estimation of candidate improvements on addressing bottlenecks and lowering transportation cost

II: Problem Statement

As individual states and different federal agencies begin developing candidate projects that are eligible for freight infrastructure investment dollars, there exist a need for a mechanism of evaluating how specific investments improve export competitiveness via mitigating bottlenecks or significantly lowering transportation costs. This research effort addresses that need by developing a model of several key agricultural export corridors that allows estimation of candidate improvements on addressing bottlenecks and lowering transportation cost.

III: Report Structure

This initial draft research report focuses primarily on descriptive information regarding four primary agricultural export supply chains, including:

a. Soybeans
b. Soft White Wheat
c. Broilers
d. Tree Nuts

Each of these export supply chains are unique in terms of geographical concentration of production/processing, transportation infrastructure utilized and export corridors and ports accessed. This information provides context around the modeling approach to be selected. This is followed by a review of different modeling approaches, to also provide background information related to the strengths and limitations of each approach and required data detail. Not included in this early draft are the different types of potential infrastructure investments that are most advantageous for each supply chain. This information will be included in subsequent drafts, as information is collected from different constituents representing each supply chain.

IV: Selected Key Agricultural Export Supply Chains

The United States is a major producer and exporter of many different agricultural commodities. This reality is primarily due to a combination of productive resources in land/climate, available capital, technology and also largely the product of an efficient multimodal transportation system that connects production to distant markets. However, the efficiency of that domestic multimodal transportation system has diminish with time, primarily due to limited public infrastructure investments to support the aging transportation system. These public transportation system investments have not kept pace with growth in freight demand. As a result, the reliability and efficiency of that system has decreased over time, as reflected in and the costs to move agricultural commodities increasingly costly to move agricultural commodities across the nation. In order to address the specific transportation needs of the following agricultural products, we first provide here a brief overview of the supply chains (production and transportation) of four agricultural commodities: soybeans, wheat, broilers, and tree nuts.

U.S. Soybean Supply Chain

Over 100 million tons of soybeans are produced in the U.S. each year (100,739,520 in the 2013-2014 crop year). The vast majority of production occurs in about half of the states, with about 96 percent occurring in the Midwest region and along the Mississippi river. About 20 percent of the harvest each year is shipped immediately to markets or processing plants via truck, rail, barge, or port container. The remainder is stored either on site at the farm or at a nearby elevator for later sale and distribution. Ultimately, soybeans are transported to one of three main types of market locations: domestic destinations for feeding, domestic destinations for processing, or international locations via export channels (mainly ports). Shipments from on-farm storage are typically routed via elevators before they are exported, but transfers to rail or barge and deliveries to processing plants may come either from elevators or from on-site farm storage directly. On average, soybeans are transported 2.4 times and travel an average of 667 miles before arriving at either an export facility or a processing plant. Generally, about 51 percent of soybeans are processed domestically into other goods (either meal or oil, which are then either exported or transported to domestic markets) and 45 percent are exported without being processed. (Informa Economics, 2016)

For short hauls within a state or between states, trucks are the main mode of transportation. 83 percent of soybean shipments to domestic destinations are performed by trucks. Conversely, 71 percent of export-bound shipments are transported via either rail (29 percent) or barge (42 percent). The average miles for shipments moving directly from a farm to a port or processing facility by truck is about 33. The average truck miles from farms to elevators is 35 and from elevators to a port or processing facility is 66. The average truck miles from a farm or from an elevator to either a barge or a rail facility is 45. Overall, soybeans that end up at either a processing facility or a port travel an average of 74 miles by truck.

Twenty-nine percent of all soybeans produced are transported an average 1,323 miles by rail. Rail movements of soybeans are destined primarily for export, with a small portion arriving at domestic processing facilities. For years, the expansion of shuttle train facilities in the Pacific Northwest has been drawing rail shipments of soybeans away from the Gulf, but this shift has recently stabilized at a new equilibrium. 72 percent of rail shipments of soybeans are currently directed to the Pacific Northwest and travel an average of 1,700 miles. These soybeans are the major supply of exported soybeans to Asian markets. 14 percent of rail shipments travel an average of about 900 miles to arrive in Louisiana for exports via the Gulf of Mexico. About 7 percent of rail shipments travel an average of 400 miles to be transloaded to barges and about 8 percent travel an average of 600 miles to be delivered to processing plants.

Seventeen percent of soybeans produced are shipped via barge. North Dakota, South Dakota, Nebraska, Kansas, and Michigan are slightly further from the Mississippi river and are the only major soybean producing states to not transport any soybeans by barge. The rest of the soybean producing states either transport long-haul soybeans by a combination of rail and barge or do not have any major outgoing shipments of soybeans. Of the soybeans transported by barge, 90 percent are shipped an average of 1,000 miles to be exported and 10 percent are shipped an average of 535 miles to be delivered to processing plants. Barge transportation has been shifting from the upper Mississippi and Illinois River origins toward the lower Mississippi and lower Ohio Rivers. Plenty of supply still exists in the upper regions but the river infrastructure is unreliable and too shallow up north, especially with the expansion of larger-capacity barges with deeper hulls that reduce average shipping costs for barges.

Around 45 million tons of soybeans are exported each year. Figure 1 shows the breakdown of all soybean exports by export position. 59 percent of exports ship out via ports in Louisiana. 26 percent of all soybean exports go through ports in the Pacific Northwest. The next two images show the final destination of soybean exports by bulk and container transport. According to the Bureau of Transportation Statistics (2017), the average freight revenue per ton-mile from 1990 to 2004 is $1.57 for barge, $2.40 for rail, and $13.37 for truck. Data is unavailable after 2004 for barge, but the rate for truck in 2007 is $16.54 and for rail in 2014 is $4.05. As barge is generally less expensive than rail, shippers to whom barge is accessible will tend to ship by barge. Shippers who are farther from the river will ship by rail because the cost of trucking to barge facilities is too high. In the case of soy, soy produced near the Mississippi river will tend to ship via the river and beyond a certain distance inland, most remaining soy is shipped via rail to the Pacific Northwest. In the event of a shutdown or major disruption or slowdown in one of these shipping routes, the boundary between production locations that ship to one outlet or the other with shift such that more soy will be shipped via the alternate route until that route has reach capacity. Such delays and disruptions can be devastating to soy producers in the United States who have a relatively brief time window in which they can viably sell soy on the world markets, which distribution is shown in figures 2 and 3. United States soy is generally more expensive than Brazilian soy and foreign buyers (mainly in the Chinese market) will only buy US soy in the season when Brazilian soy is unavailable.

Figure 1: U.S. Soybean Export Channels 2013-2015

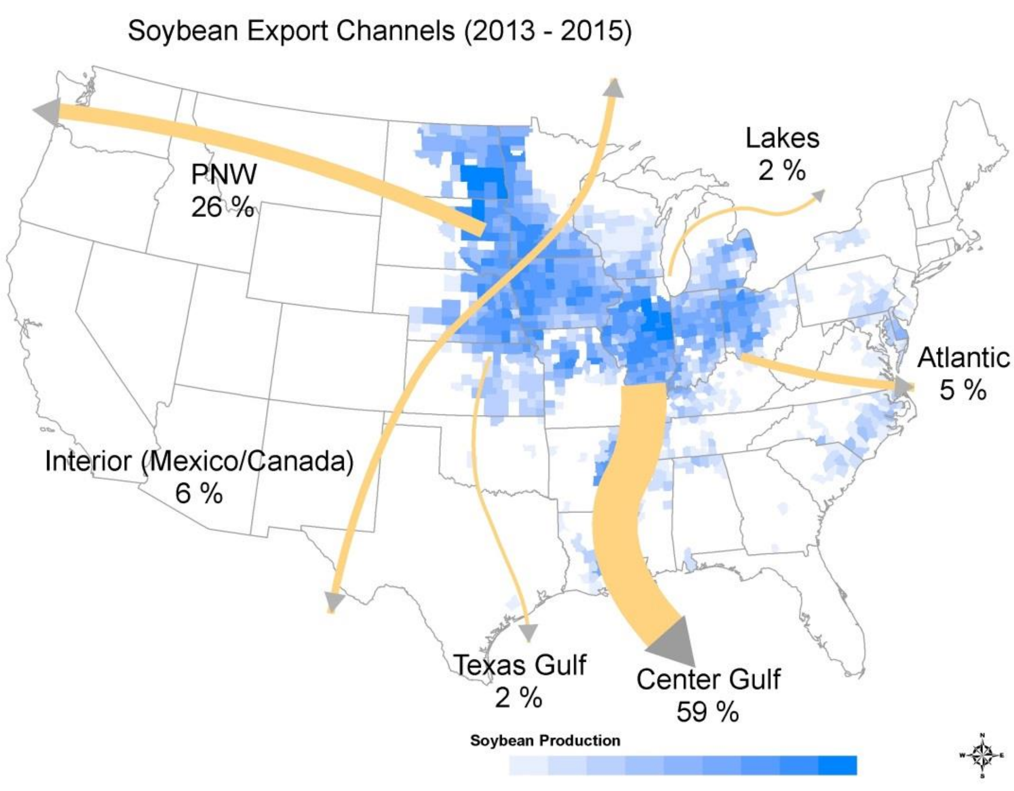


Figure 2: U.S. Bulk Soybean Export Destination Countries, 2013 – 2015

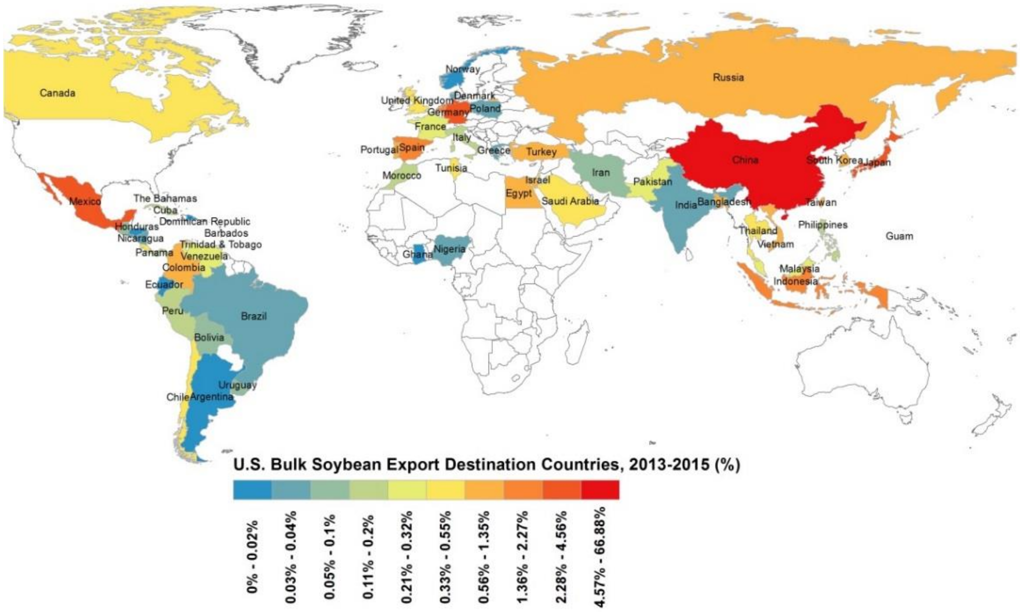
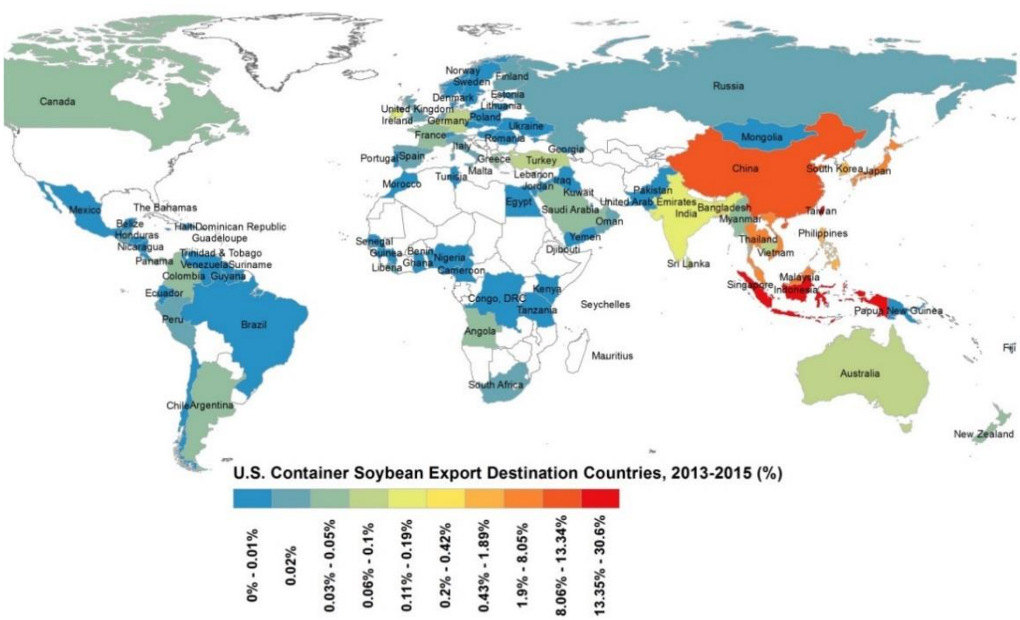


Figure 3: U.S. Container Soybean Export Destination Countries, 2013 – 2015



U.S. White Wheat Supply Chain

Around 60 trillion tons of wheat are produced in the U.S. each year (62.9 trillion in the 2015-2016 harvest). Of this, about 43 percent is exported and 55 percent is consumed domestically. Wheat is grown in almost every state in the United States. The majority (61 percent) is grown in the plains region in states between the Mississippi River and the Rocky Mountains.[1] An additional 17 percent is grown in the Great Lakes and Mississippi River regions and 13.5 percent is grown in the Pacific Northwest.

In 2013, 36 percent of wheat was exported via the Pacific Northwest, 27 percent via Texas, and 29 percent via Mississippi gulf ports. (USDA-AMS, 2014). Of the wheat that was used in the 2011-2012 harvest year (rather than reserved as future stock), 42.2 percent was used as food, 10.7 percent was used for animal feed or for seed, and 47.1 percent was exported. (USDA-ERS, 2013).

The modal split for all wheat movement in the U.S. is 67 percent rail, 15 percent barge, and 18 percent truck. For export destinations, the split is 67 percent rail, 29 percent barge, and only 4 percent truck. For domestic destinations, the split is 67 percent rail, 1 percent barge, and 32 percent truck (USDA-AMS, 2013).

The only two navigable river systems for barge transport in the U.S. are the Mississippi River system (including the Missouri River and the Arkansas River) and the Columbia River system. For areas relatively close to either of these systems, barge and rail providers compete for market share of wheat transport. However, much of the northern and central plains are isolated from the river systems and must rely solely on rail for long-haul transport. The following figure shows the distribution of wheat exports by export channel. 43 percent of exported wheat is transported from the Northern Plains and Pacific Northwest regions to ports in the Pacific Northwest. Another 27 percent is exported via the Texas Gulf. Only 19 percent is transported down the Mississippi River to the Center Gulf ports.

According to the Bureau of Transportation Statistics (2017), the average freight revenue per ton-mile from 1990 to 2004 is $1.57 for barge, $2.40 for rail, and $13.37 for truck. Data is unavailable after 2004 for barge, but the rate for truck in 2007 is $16.54 and for rail in 2014 is $4.05. As barge is generally less expensive than rail, shippers to whom barge is accessible will tend to ship by barge. Shippers who are farther from the river will ship by rail because the cost of trucking to barge facilities is too high. This competition between rail and barge is especially important for producers and shippers in the Mississippi River and Columbia River regions. In both cases, a boundary exists around the rivers such that all producers and shippers beyond the boundary must rely solely on truck-to-rail shipments to either the Texas Gulf or ports in the Pacific Northwest. As discussed in the case of soybeans, a disruption to any of the major routes will shift this boundary either closer to or further from the river systems and put a strain on the capacity of alternative routes (USDA-AMS, 2015; American Farm Bureau Federation, 2015).

A major consideration for grains being shipped via rail from the Midwest and Northern Plains to the Pacific Northwest is the recent increase in crude oil production in the Northern Plains region (particularly in North Dakota). The growth of oil production has pushed the capacity of rail shipments in this region to its limits and made this route more susceptible to major disruptions as in the major shutdowns that occurred in the 2013-2014 harvest season.

[1] The plains region as used here does not include states that directly border the Mississippi River.

Figure 4: Wheat Export Channels, 2013 – 2015

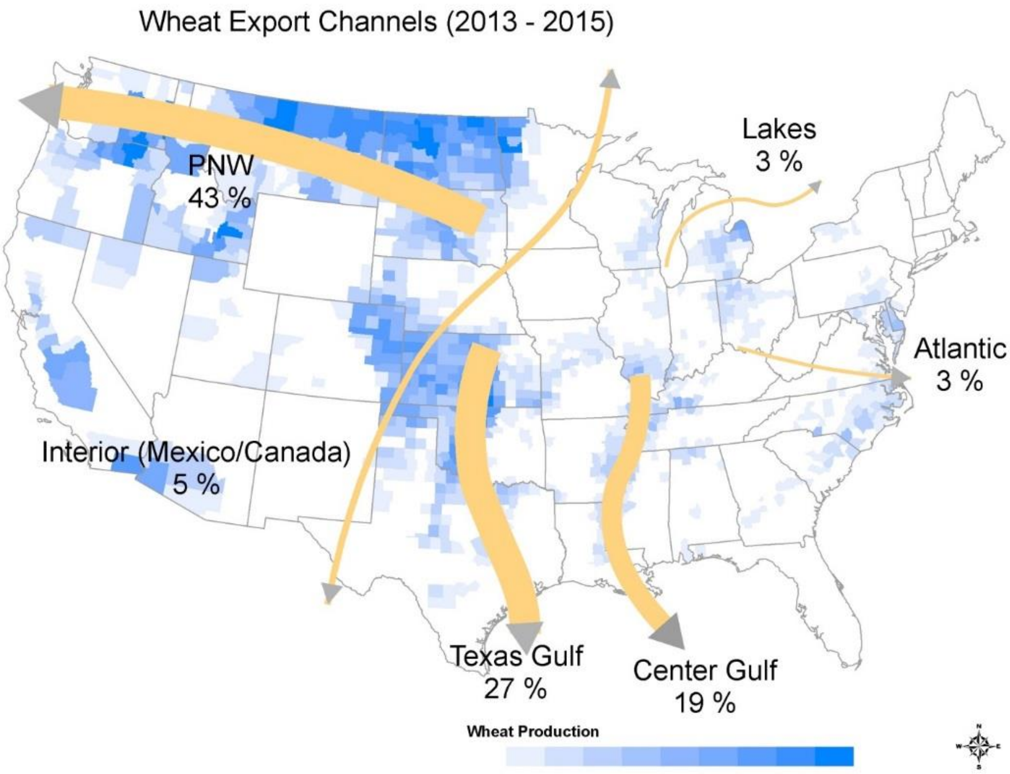


Figure 5: U.S. Bulk White Wheat Export Destination Countries, 2013 – 2015

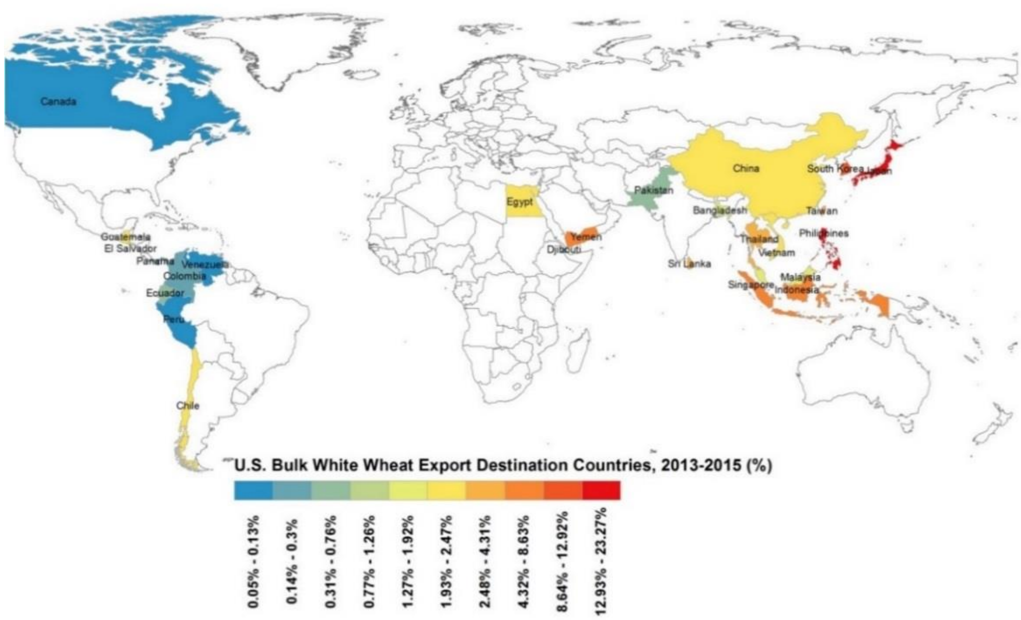
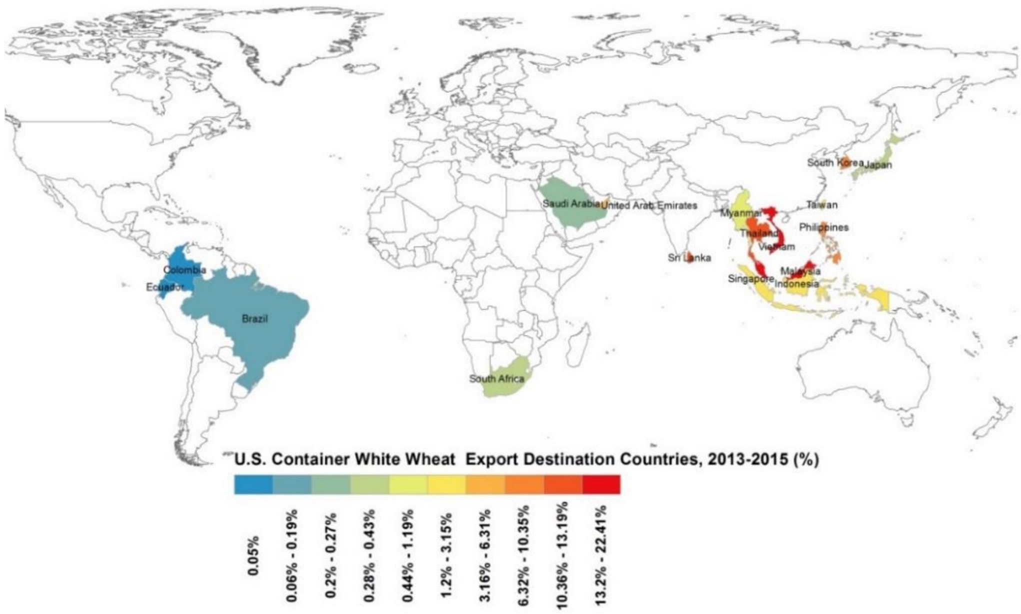


Figure 6: U.S. Container White Wheat Export Destination Countries, 2013 – 2015



U.S. Broiler Supply Chain

The United States has the largest broiler chicken industry in the world. According to National Chicken Council (2016), approximately thirty-five companies are involved in the business of raising, processing, and marketing chickens on a “vertically integrated” basis. Approximately 95 percent of broiler chickens are produced on 25,000 family farmers, with the remaining 5 percent raised on company-owned farms. The average grower has four broiler houses, with a total value (including the land) of about $1 million (USDA-ERS, 2014). In 2015, almost 9 billion broiler chickens, weighing 53 billion pounds live weight, were produced in the United States. This amounts to more than 40 billion pounds of ready-to-cook, marketed chicken product. Broilers are produced across the United States in over half of the states, but 88 percent of broilers are produced in the Southern states. The top 6 broiler-producing states are Georgia, Arkansas, Alabama, North Carolina, Mississippi, and Texas, which together produce 66 percent of U.S. broilers (measured in 2010). Americans also consume more chicken than anyone else in the world – more than 90 pounds per capita in 2015 (National Chicken Council, 2016).

Poultry meat processing includes the delivery of live birds, shackling, stunning, bleeding, scalding, picking (removal of feathers), removal of feet, head, neck and oil glands, evisceration (removal of internal organs), carcass washing, chilling, cutting up and deboning, and further processing for added value (such as forming, curing, smoking and cooking of products) (U.S. Poultry, n.d.). From 1999 to 2009, an average of 11 percent of broilers were marketed whole, 43 percent were marketed as cut-up parts, and 46 percent were marketed after further processing (http://www.nationalchickencouncil.org/about-the-industry/statistics/how-broilers-are-marketed/).

In the United States, most food is transported by truck, often refrigerated. However, meat, poultry, and egg products may be transferred to and from other modes of transportation during shipment and held at intermediate warehouses as well as at transfer or handling facilities, such as airports, break-bulk terminals, and rail sidings. (USDA-FSIS, 2005, p.4).

About 19 percent of broiler production was exported to other countries in 2015. The top 3 export destinations (by value) in 2015 were Mexico, Canada and Hong Kong. The export destinations and the location of major export ports are illustrated in Figures 7 and 8. Most export locations are located near the majority of production sites in the Southern states along both the Atlantic and Gulf coasts. Outside of this region, California is also a major producer and exporter of broilers with 20 percent of broiler exports going through either Oakland or Los Angeles.

Figure 7: U.S. Broiler Export Destination by Countries, 2013 – 2015

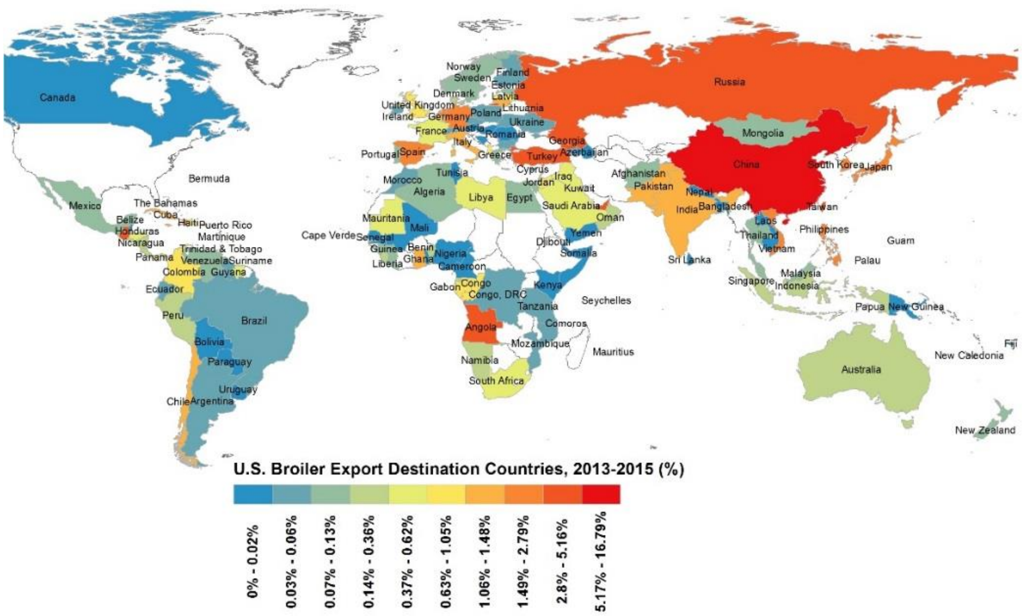
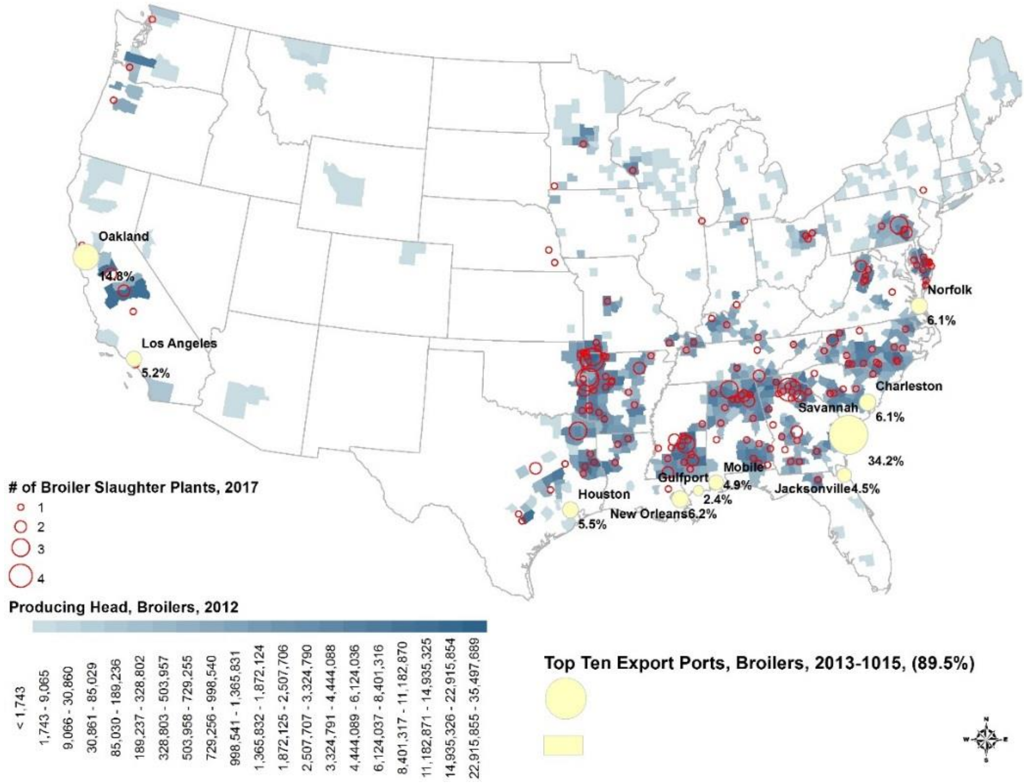


Figure 8: Major U.S. Broiler Export Ports, 2013 – 2015

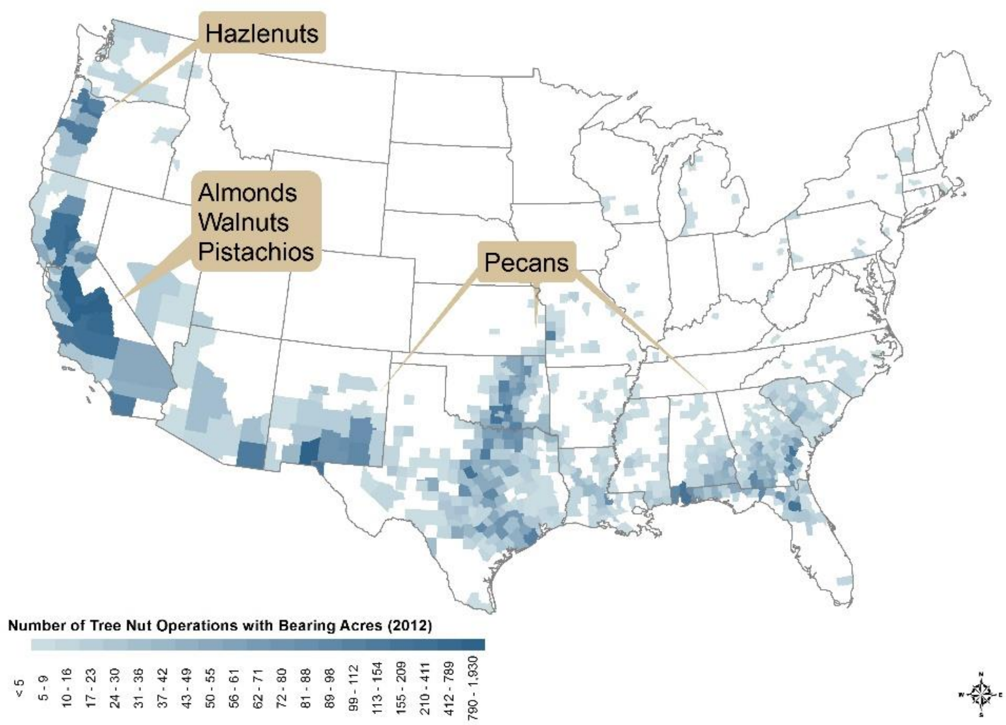


U.S. Tree Nut Supply Chain

The United States is second only to China in world production of tree nuts, producing more than one-tenth of the world's tree nuts. Each year, the U.S. produces around 1.3 million acres of tree nuts (1.47 million in 2015), the value of which totals around $7 billion ($7.7 billion in 2015). By acreage, 63 percent of tree nuts produced are almonds, 21 percent are walnuts, 13 percent are pistachios, and 2 percent are hazelnuts (USDA-NASS, 2017). Pecans are also a major tree nut produced in the U.S., valuing $517 million in 2014 (about 4 percent of the value of all tree nuts) (http://www.agmrc.org/commodities-products/nuts/pecans/).

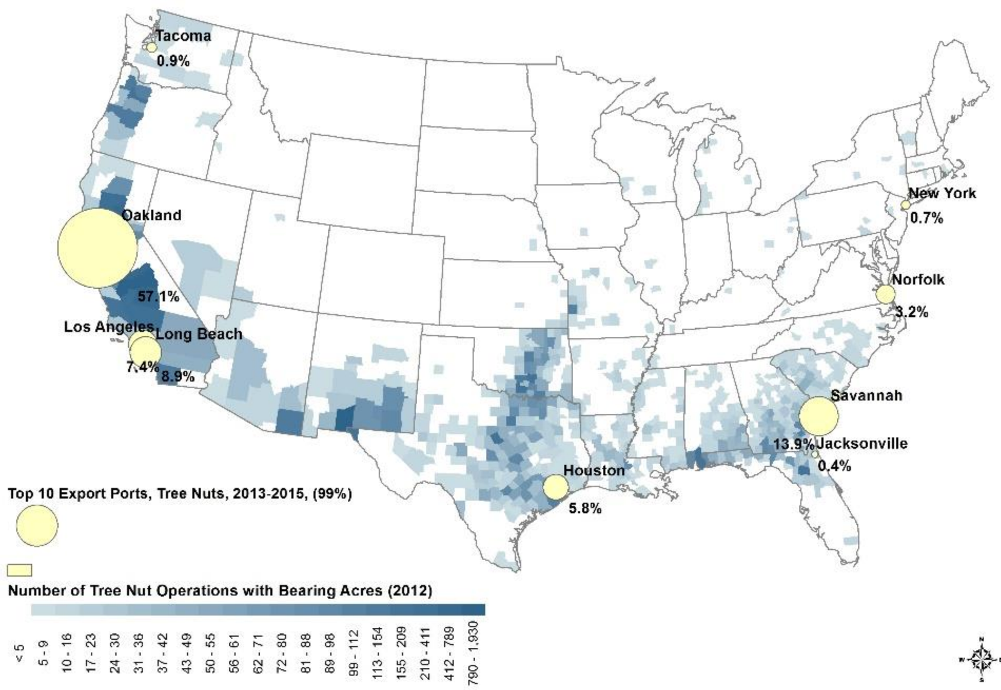
As illustrated in Figure 9, the production of tree nuts is distributed across the western and southern regions of the U.S. Almonds, walnuts, and pistachios are mainly grown California and other areas in the Southwest; hazelnuts are mainly produced in Oregon; and Pecans are produced across the Southern states. The diverse types of tree nuts have different processing and storage requirements. Usually, processors and handlers are distributed near orchards for efficient handling. Once the tree nuts are shelled and processed, they are stored in a controlled environment.

Figure 9: Number of Tree Nut Operations with Bearing Acres (2012)



Tree nut exports averaged over 45 percent of U.S. tree nut supplies during the 2000s (up slightly from the 1990s). Almonds formed nearly 70 percent U.S. tree nut export volume in recent years, averaging over 970 million pounds (shelled basis), or almost three quarters of world almond exports. Following almonds are walnuts and pistachios with over 10 percent and about 7 percent, respectively, of total tree nut exports. The main export destinations for tree nuts are visualized in Figure 10. The majority of exported tree nuts are exported through the ports in the San Francisco Bay Area, followed by Los Angeles and Long Beach. In the South, tree nuts are exported mostly via Savannah, Georgia and Houston, Texas.

Figure 10: Top 10 Export Ports for Tree Nuts, 2013 – 2015



The major export destinations of U.S. tree nuts are Hong Kong, Japan, India, China, South Korea, Vietnam, and Taiwan in Asia (49 percent); Spain, Germany, and the Netherlands in the European Union (31 percent); the Middle East and Africa (10 percent); and Canada and Mexico in North America (9 percent) (See Figures 11 and 12). Excluding domestic consumption, the distribution of exports in 2016 are listed as follows (USDA-FAS, 2016).

Figure 11: U.S. Tree Nut Export Destination Countries, 2013 – 2015 (USDA-ERS, 2016)

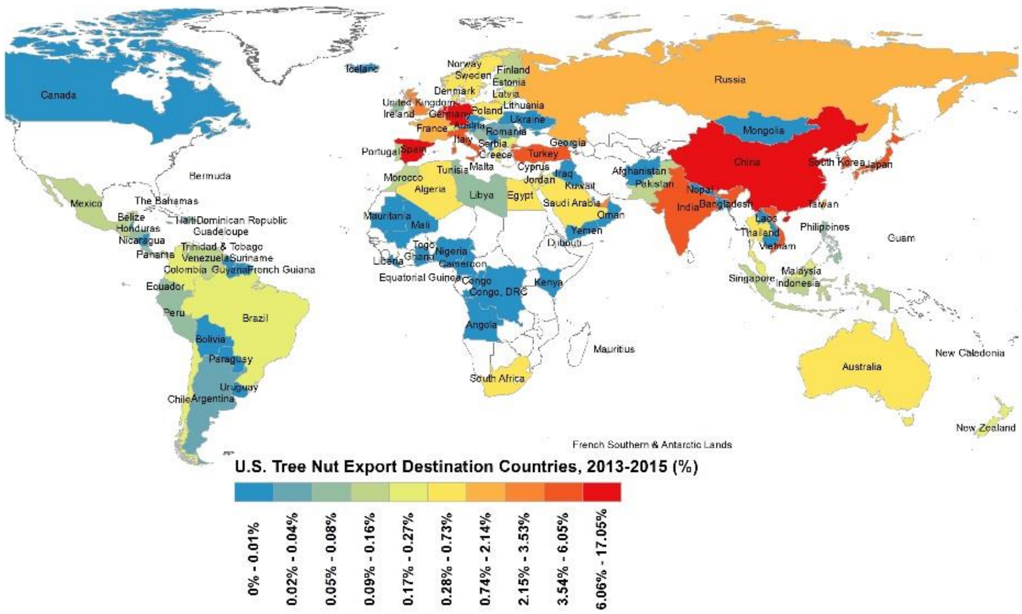
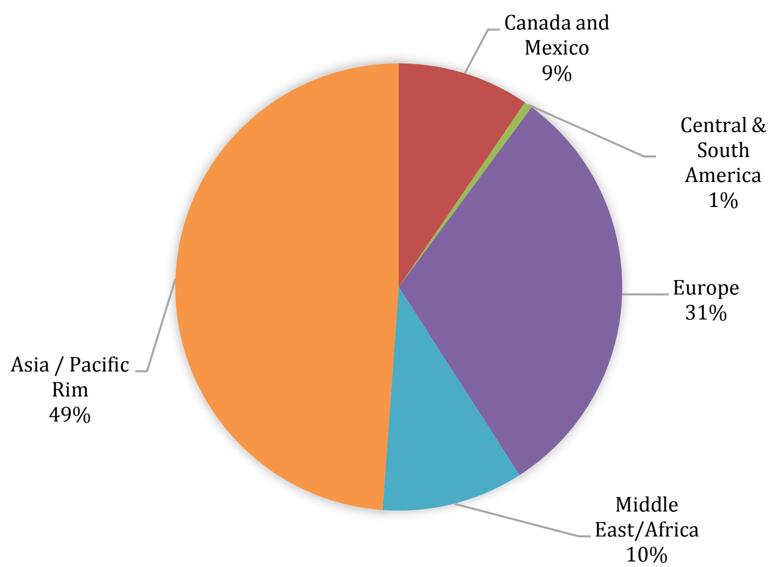


Figure 12: Share of U.S. Tree Nut Export Destinations, 2013 – 2015 (USDA-FAS, 2016)

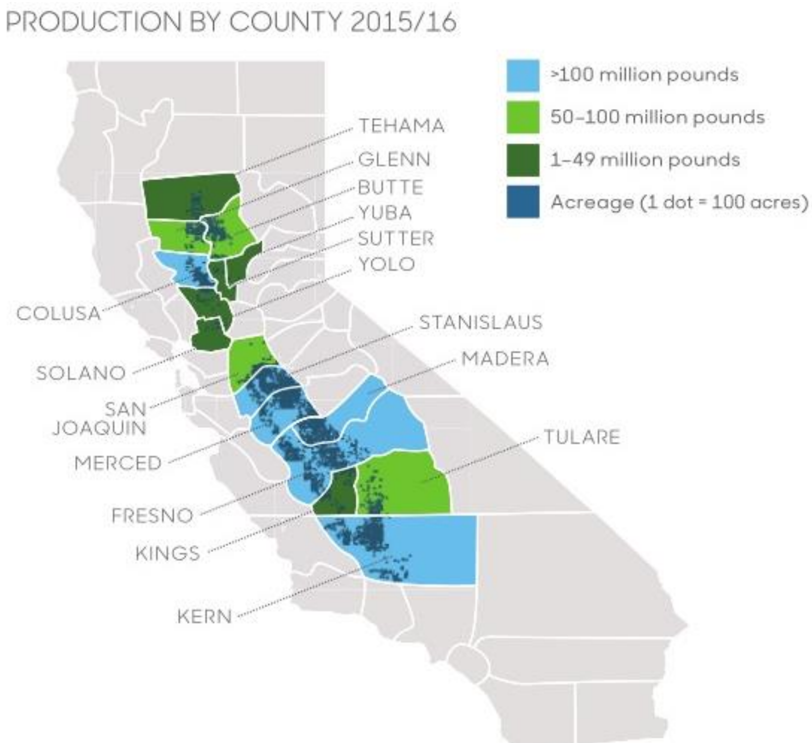


Because of the relative nearness of production locations to international ports, most tree nuts are transported from production to processing and from processing to export via truck. According to the 2002 Commodity Flow Survey, 90 percent of all processed fruit, vegetables, or nuts were transported by truck (https://www.ams.usda.gov/sites/default/files/media/RTIReportChapter2.pdf). For the 2015-2016 year, the average rate for refrigerated truck transport was $4.75 for the first 500 miles, $2.25 up to 2,500 miles, and $1.23 per mile after 2,500 (USDA-AMS, 2016).

Almonds

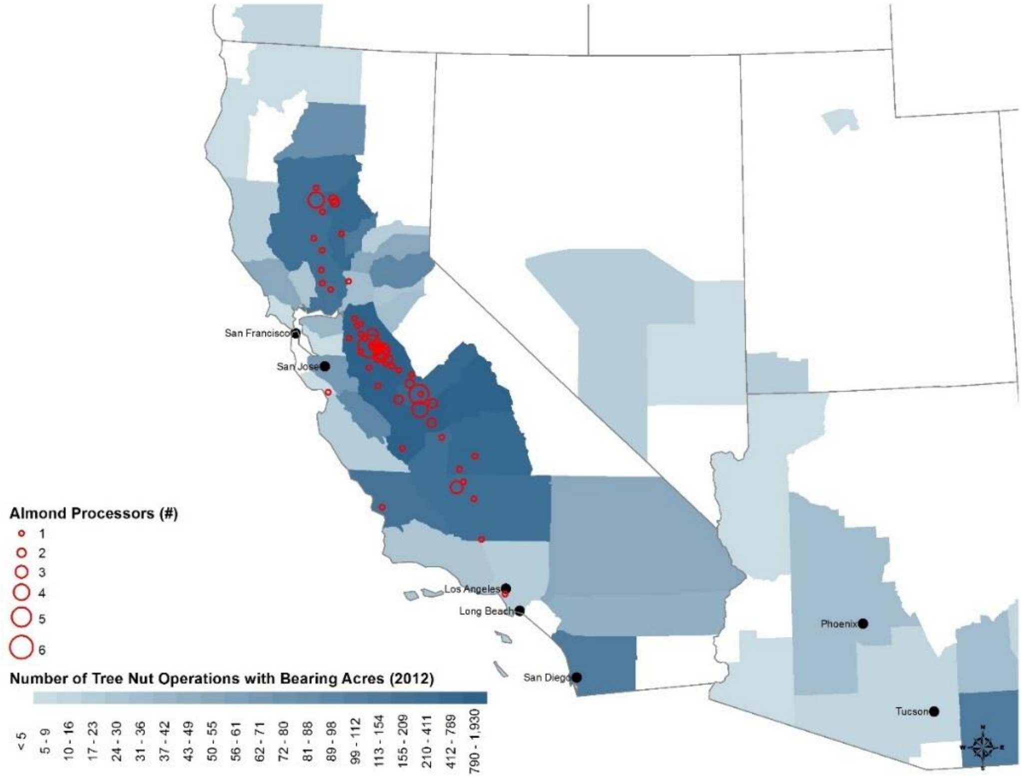
California accounts for 99 percent of the commercial U.S. supply of almonds (Jerome, 2003), and over 80 percent of the world's supply. The major varieties, in terms of tonnage, are Nonpareil, Carmel, Butte, Monterey, Butte/Padre and Fritz (Almond Board of California, 2016, p.33). According to 2012 USDA Agricultural Census, there are around 6,800 California Almond farms; many of whom are family-owned businesses located in the Central Valley region as illustrated in Figure 13 (ABC, 2016, p.11). Around 100 California Almond handlers process almonds (Almond Board of California, 2016). The distribution of almond handlers is illustrated in Figure 14.

Figure 13: Distribution and Production of Almond Growers



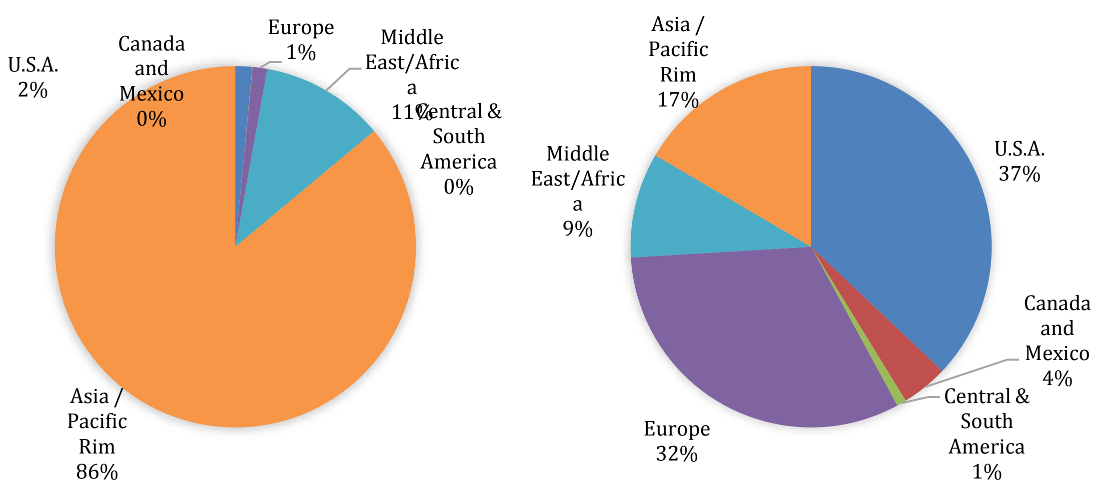
(Source: Almond Board of California, 2016. Almond Almanac: An Annual Report.)

Figure 14: Location of Almond Handlers



According to Almond Board of California (2017), 98 percent of in-shell almonds and 63 percent of shelled almonds are exported, and the rest are consumed domestically. The year-to-date (August 2016 to March 2017) share of export destinations are depicted in Figures 15 and 16.

Figure 15: Export Destinations of In-shell (left) and Shelled (right) Almonds

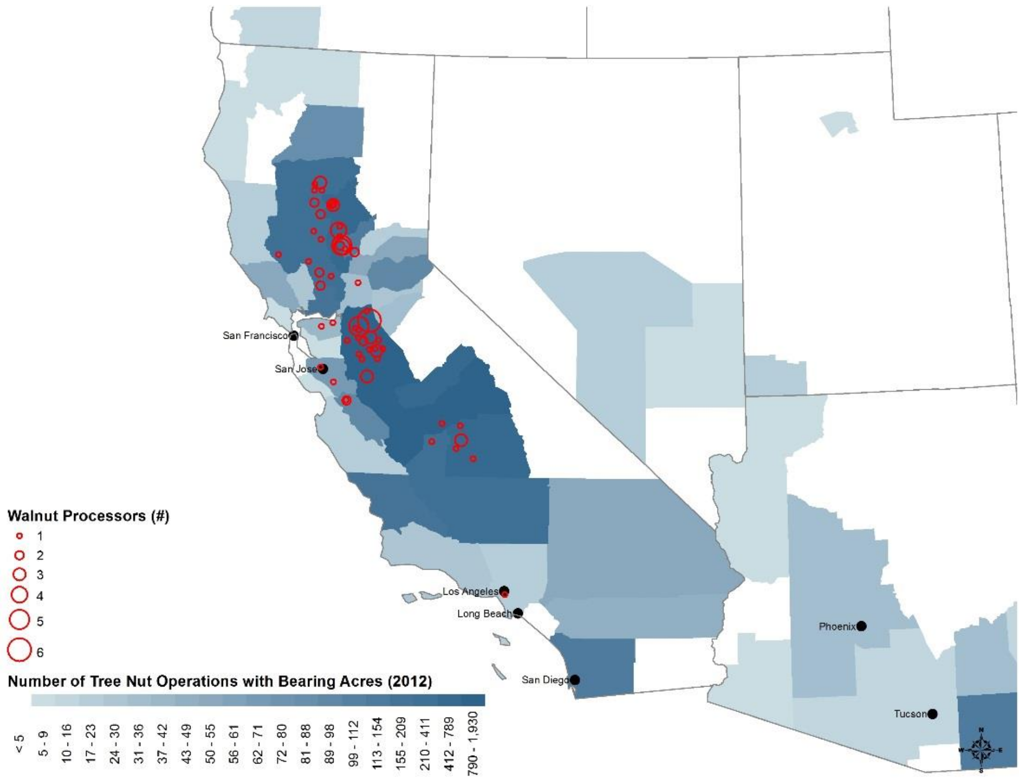


Walnuts

More than three quarters of the world's walnuts are grown in California. The six major varieties of walnuts are Chandler, Harley, Howard, Tulare, Serr and Vina. Most are grown in San Joaquin and Sacramento valleys (Marks, 2016). Domestically, California accounts for 99 percent of commercial U.S. supply, with Oregon and Washington taking up the remaining production. (Geisseler and Horwath, 2016).

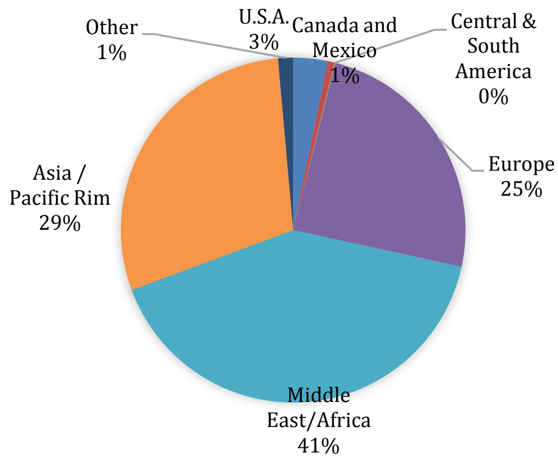
After being harvested, walnuts are transported either to processors or to nearby packing plants for size, color grade, and quality sorting. The nuts are either stored as in-shell products or mechanically cracked into shelled products ready for shipments. The distribution of processing plants is depicted in Figure 17.

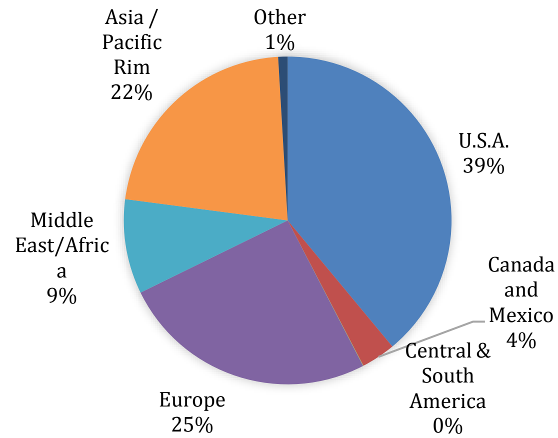
Figure 16: Location of Walnut Processors



According to California Walnut Board (2017), about 97 percent of in-shell walnuts and 61 percent of shelled walnuts are exported, with the rest being consumed domestically. The year-to-date distribution of export destinations from September 2016 to March 2017 are illustrated in Figures 18 and 19.

Figure 17: Export Destinations of In-shell (left) and Shelled (right) Walnuts

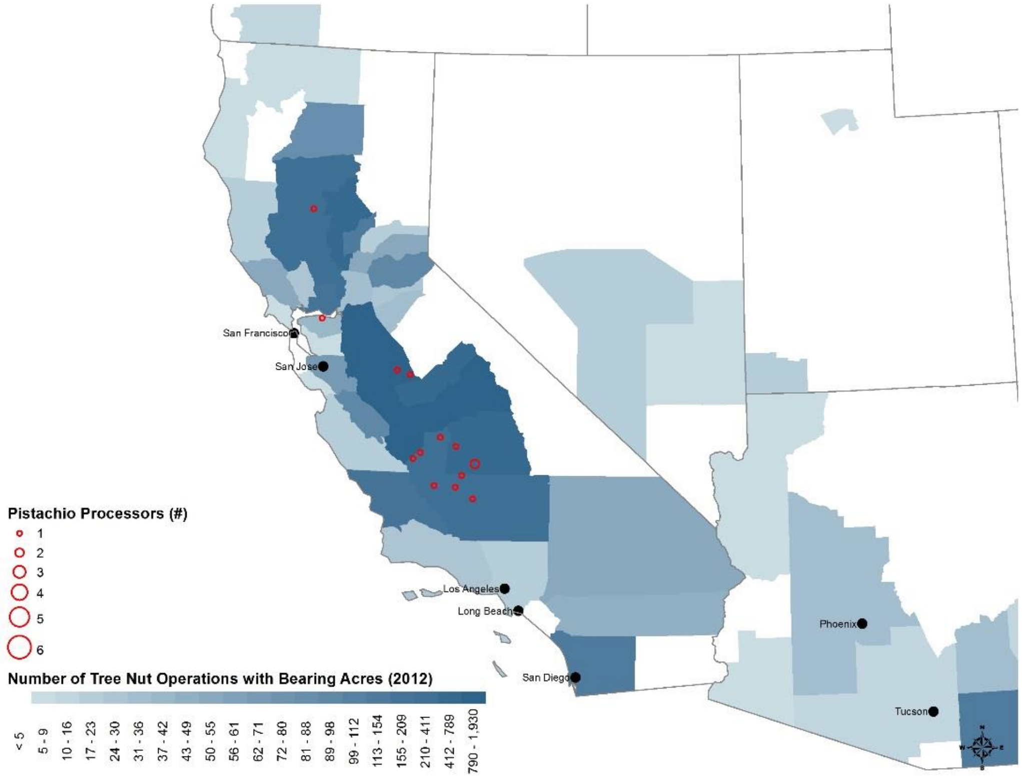




Pistachios

Approximately 98 percent of U.S. pistachios are produced in the San Joaquin Valley of California. The rest are produced in other Southwestern states such as Arizona, New Mexico, Texas and Utah (Boriss, 2015). Within 24 hours of mechanical harvesting, pistachios are transported to processing plants for cleaning, drying, sorting, and storage. Figure 17 displays the spatial distribution of pistachio processors in the Central Valley region of California.

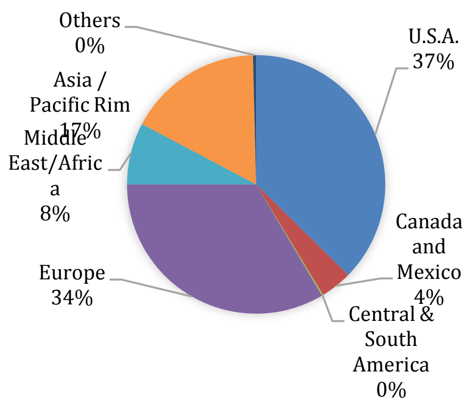
Figure 18: Location of Pistachio Processors

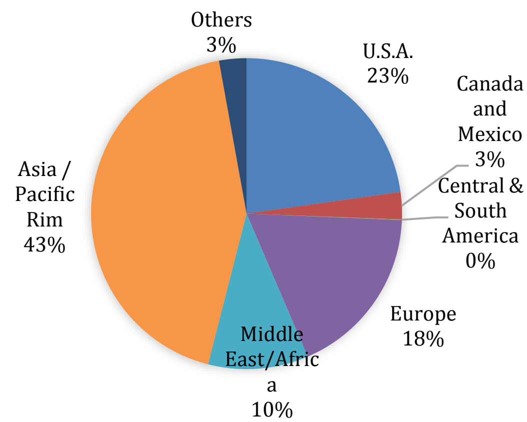


For domestic transportation, pistachios are transported nearly exclusively by truck. Over 90 percent of production in California is within two hours of a processing facility with the furthest producers only 6 hours from the nearest processor (California Pistachio Research Board, 2009).

United States exports of pistachios are about equal with exports from Iran, and both are followed by other Middle-East countries such as Syria and Turkey (Alston et al., 2005). According to Administrative Committee for Pistachios (2017), 37 percent of in-shell and 23 percent of shelled pistachios are consumed domestically and the rest are exported as illustrated in Figures 18 and 19.

Figure 19: Export Destinations of In-shell (left) and Shelled (right) Pistachios



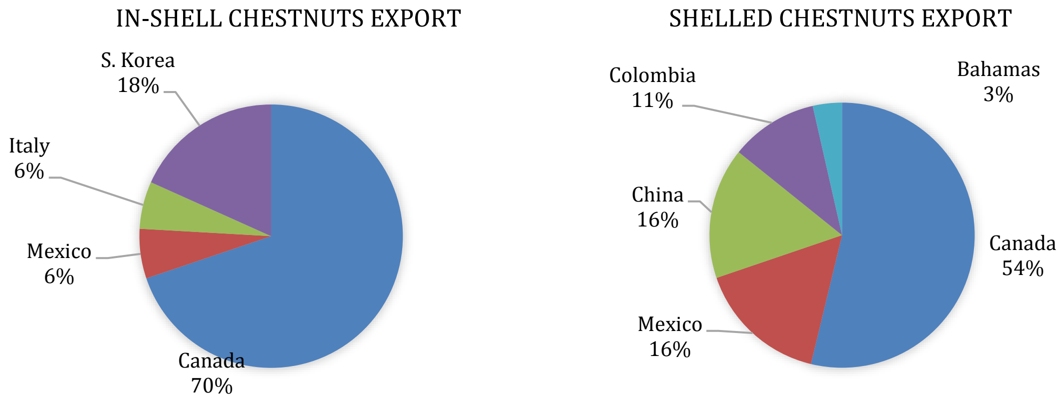


Chestnuts
U.S. chestnut production is less than 1 percent of total world production. A total of 919 farms produce chestnuts on more than 3,700 acres spread widely across the United States. The states with the highest production of chestnuts are Michigan, Florida, California, Oregon, Virginia, and Iowa (Vossen, 2000). According to a study commissioned by Ross and Victor (2012), large commercial farms only dedicate a small percentage of the farm to chestnut production to diversify the risks associated with growing chestnuts, while hobbyists and retirees tend to devote a more sizable proportion to it.

A survey conducted by Gold, Cernusca and Godsey (2006) find that 63 percent (57 out of 90 of the chestnut growers) use their own vehicles to transport chestnuts to the market. The percentage was even higher in Ross and Victor (2012), for which 87.5 percent (28 out of 32 farmers) transport the chestnuts in their own truck. The remaining producers sell all products on farm or share transportation with another producer.

Given the miniscule production of chestnuts in comparison to other types of tree nuts, consumption is mainly based on local production or imports. In 2011, U.S. imported 3,781 metric tons of chestnuts valued at $12.4 million (Agricultural Marketing Resource Center, 2015). Nevertheless, chestnuts are exported in a limited scale. In 2016, Chestnut exports constituted less than 0.05 percent of the overall U.S. export of tree nuts (Foreign Agricultural Service, United States Department of Agriculture, 2017). Figure 20 shows distribution of country destinations for chestnut exports.

Figure 20: 2016 Export of U.S. Grown Chestnuts (left: in-shell; right: shelled)



V: Review of Literature: Modeling Network Investments

When considering how to evaluate and rank potential infrastructure investments, one must consider 1) how the investment will change the existing network, 2) what metric to use for ranking projects, and 3) how to evaluate the appropriate metric. In this section, we first review the literature on strategic network design, which provides a background for how to model a complex transportation network. We then review the different methods for evaluating economic impacts within a region.

Network Design

Network design literature seeks to determine optimal infrastructure development and the optimal locations for transportation network terminals. Generally, the network is first modelled in some form such that relevant costs can be calculated; costs may include direct transportation costs, value of time estimates, and/or environmental impacts. Then some optimization technique—e.g., a mathematical algorithm such as integer programming (Rutten, 1998; Macharis, 2004; Racunica and Wynter, 2005), a heuristic (Arnold et al., 2004; Groothedde et al., 2005), and/or a series of simulations (Meinert et al., 1998; Tan et al., 2004) —finds a configuration that meets some certain criteria (e.g., minimizes costs).

For instance, Macharis et al. (2011) create a fully integrated decision support tool for policymakers in Belgium. The tool combines a virtual network with shortest-path algorithms and discrete-event simulation software. A virtual network uses GIS software to represent not only the links and nodes in the actual transportation network, but also each operation that can be performed on a given link or node. For example, unloading at a terminal is represented by a different virtual node than transshipping through that same terminal. In this way, total costs can be calculated that incorporate all of the unique services that are used along the way for a specific shipment infrastructure (Jourquin et al., 1999). A virtual network like this can also be used estimate the effect of changes to the network on things like road traffic (Klodzinski and Al-Deek, 2004) or modal split (Tan et al., 2004; Parola and Sciomachen, 2005).

Until relatively recently, many network models did not account for the possibility of multiple mode options (Bontekoning et al., 2004). As many shippers in the United States must make the choice between truck, rail, and/or barge, the intermodal aspect of a network model is extremely important. Models that do account for the choice between modes must include some kind of flow assignment model to determine how much of the demand for transportation will be split between each mode (e.g., Floden, 2007; Iannone, 2012). The complexity of these models varies. For example, Maia and do Couto (2013) include a consideration both for capacity constraints and for variable perceptions of costs in their model. Some models are then able to include a bi-level analysis that incorporates a flow assignment that responds to changes in the network and then some kind of optimization algorithm to determine which changes best meet some criterion; e.g., maximized benefit-cost ratio (Zhang et al., 2008; Yamada, 2009).

Caris et al., (2008), Caris et al., (2013), Zhang et al. (2013), and SteadieSeifi et al. (2014) provide diverse reviews of network design literature and the conclusions from these analyses are summarized below. The reader is referred to these reviews for a more detailed analysis of the literature.

Caris et al., (2008) conclude that little analysis has been done with respect to metaheuristics for determining which operations research approaches are the best for certain problems. The authors also call for more models that incorporate cooperation between different types of decision makers or integrate the problems faced at different time horizons (e.g., terminal network design and service network design). Caris et al. (2013) then remark that the literature since the 2008 review has developed more mathematical models for solving network problems, incorporated more dynamic features into analyses, and given more focus to environmental impacts than previous papers. According to this review, the main hurdles that future researchers will have to overcome are the coordination of diverse actors, the large and complex scale of network projects, and the limited availability of good data (due to both proprietary concerns and difficulty in data collection/transmission).

According to Zhang et al. (2013), many problems still exist with the current network design models. These include a lack of consideration for economies of scale in terminal handling costs, a lack of connection between terminal network designs and service network designs, a lack of realistic demand models, and long computation times.

In SteadieSeifi et al. (2014)'s review of the current network design literature, the most common consolidation plan is the hub-and-spoke network and most research analyzes the optimal location-allocation of such networks. For an extensive study of hub location problems, the review directs the reader to Alumur and Kara (2008). SteadieSeifi et al. (2014) also outline the various types of hub-and-spoke allocation models (single-allocation, multi-allocation, r-allocation, and hierarchical allocation) and the solution concepts employed to solve such models. The authors point out that these problems are complex and current solution algorithms are inadequate and inefficient but improving. Although adding complexity will make the models even harder to solve, the authors suggest several elements that are virtually missing from current network design models. These include capacity restrictions, fixed costs of building hubs, transshipment (switching between modes) and associated costs, empty unit storage, cooperation and competition between carriers, and environmental issues. Additional holes in network design literature include: a more diverse study of various consolidation approaches (most are hub-and-spoke), more trade-offs between multiple objectives (e.g., cost and time), and more dynamic and stochastic models.

Economic Impact and CGE Modeling

Most network design models discussed above rely on cost minimization or other similar benefit-minus-cost calculation. Often, the consolidation of every relevant impact into a single cost metric can become extremely complex and difficult. In a survey of Benefit-Cost Analysis professionals, Mouter et al. (2013) find that more than half of the survey respondents think that “estimation of non-monetarized project effects” is the most substantive research problem, seconded by “monetarization of project effects” by almost one-fourth of them. In addition, infrastructure investment can often have secondary effects in the economy beyond direct benefits and costs. These effects, generated by efficiency gains in the network, could be manifested as changes in the number of jobs, the total output, or the value added of various sectors in the region. It is important to be able to model the relationship between primary transport benefits and potential economic growth effects (Banister and Berechman, 2001). Considering the need to model these sorts of secondary impacts, substantial use of statistical models representing the flow of dollars between industries has been used to relate transportation investments to productivity and employment.

The earliest among these models were based on Input-Output (I-O) models first developed by Nobel Prize winning economist Wassily Leontief. Despite its age, I-O is still among the most popular methods for determining economic impacts of transportation infrastructure projects and has been used in several recent studies (e.g. RESI 1998, Liu and Vilain 2004, Economic Development Research Group, Inc 2006, Guiliano et. al. 2011). Nevertheless, it comes with a set of well documented liabilities including: fixed prices, perfectly elastic supply of factors, fixed input mix, and exogenous final demand. Rose and Liao (2005) point out that because of these assumptions, I-O analysis provides only an upper bound estimate of the impacts of a policy or project. Similarly, Dwyer et. al. (2005) suggest the method has “inherent biases that overstate the impacts on output and jobs.” Attempts have been made to deal with these assumptions by extending I-O models (see Rose and Liao 2005 for examples); however, the basic problems remain.

In contrast, within the context of a Computable General Equilibrium (CGE) model, all of potentially limiting assumptions of I-O models can be relaxed at the cost of adopting a new set of assumptions. Most peer-reviewed articles dealing with the topic recommend always using CGE over I-O if possible (Seung et al., 1997; Rose and Liao, 2005; Dwyer et al., 2005, 2006; Partridge and Rickman, 2010; Cassey et al., 2011).

The seminal work on CGE modeling is attributed to Johansen (1964) and is as a blend of neoclassical theory applied to contemporary policy issues (Bandara, 1991). Shoven and Whalley (1984) developed the method into the highly useful, applied tool it is today. Typically, a CGE model is generated using a combination of classical economic assumptions (such as zero profit, market clearance, and normal goods) and regional data from a social accounting matrix (SAM). The specific parameters in the models are generally calibrated to coincide with a benchmark period (Partridge and Rickman, 2010). Some aspect of the model—e.g., lowering the cost of transporting a certain type of good—is then changed and the model is resolved as a counterfactual to the benchmark. The differences between the benchmark and counterfactual suggest how the simulated economy will shift given some change, policy or project. This method for measuring economic impacts has become popular in academic literature as well as among federal government agencies (e.g. the EPA's EMPAX-CGE), but not necessarily among state-level government agencies.

Most uses of CGE models in transportation research involve a multiregional framework that enables explicit modeling of travel costs and specific changes in sub regions (Bohringer and Welsch, 2004; Brocker, 2000; Buckley, 1992). Such multiregional analysis, however, adds a level of complexity that can create undue confusion. Conrad and Heng (2002) demonstrate that when overall benefits to society are the variable of interest, a multiregional model is unnecessary.

It is important to be aware of some common limitations of CGE models. One of the primary limitations, which has been well documented by Partridge and Rickman (2010), is that CGE models are calibrated to a single year and thus are subject to biases toward the state of the economy in that year. Another potential problem is that CGE models do not have effective means to handle the introduction of new businesses, exporting opportunities, or importing opportunities. Similarly, secession from a certain activity cannot be modeled well with a CGE. For example, if it no longer makes sense for a business or industry to operate in a given scenario, the model will still show it operating but at a very low level.

Another issue that ought to be discussed when dealing with regional policy decisions is the difference between economic impact (as measured through economic impact analysis) and net social welfare. Welfare is touted as the more appropriate metric for decision making (Abelson, 2011; Edwards, 1990); however, impact is very widely used. This is not for theoretical reasons, but rather because impacts are more readily understood by a lay audience. An impact can be stated as a change in the number of jobs—a very easy to understand and increasingly demanded performance metric. Alternatively, net social benefits are defined in terms of utility, something only economists tend to discuss. It also could be the case that impact analysis is so popular due to the long-time dominance of I-O models in regional science. Unmodified I-O models are incapable of estimating net social benefits, leaving impacts as the only available metric.

CGE models, on the other hand, can be used to directly estimate social welfare, generally by calculating equivalent variation (Hirte, 1998; Bohringer and Welsch, 2004; Nam et al., 2010). Alternatively, Dwyer and Forsyth (2009) explain that Benefit-Cost Analysis (BCA) and Economic Impact Analysis (EIA) can be married by subtracting the costs of factors of production from the impact of an event (as calculated in a CGE model) and adding the remainder to the other surpluses calculated through BCA to generate a robust, general equilibrium cost-benefit ratio. Whereas this seems somewhat round-about given that CGE models can directly estimate welfare, it is nevertheless effective.

Proposed Plan and Approach

The proposed plan to evaluate infrastructure investments that support specific supply-chains is a modified approach, leveraging past research associated with CGE modeling to capture the impact associated with the construction activities from the investment and to also measure the impact to shippers upstream of the investment. By combining these two aspects, a more complete assessment of how the investments compare can be realized. Many of the terminal location or network design models use total network costs as the bottom line and are focused on evaluating the entire network at once. It becomes increasingly complicated to include details such as modal splits, social costs, value of time, and environmental impacts. Separating the analysis into two stages means that in the first stage, we can include a more robust model of a proposed upgrade and how that upgrade will directly affect different agents in the regional economy. We can include building costs, economies of scale, tax revenues, etc. We can also include a realistic demand model based on different costs and capacity constraints. The results of this analysis will determine what elements to shock in the CGE model in order determine the overall economic impact on the region. Projects can then be compared and ranked based on total economic impact, rather than a single or composite measure of cost.

A CGE model can be used to determine the total regional change in social welfare that will occur because of the project. This can be done by first modeling the economy in a computable general equilibrium model (CGE) as it is before the change, and then shocking the model by changing certain variables that will be affected by the project. All other sectors will shift accordingly as the model finds a new equilibrium called the counterfactual. The counterfactual can then be compared to the original condition called the benchmark to produce a measure of Equivalent Variation. This allows us to examine the potential economy-wide impacts of a project or policy. After each counterfactual is modeled, a planner or analyst can compare the associated Equivalent Variation values to determine an order of priorities based on which projects will have the greatest positive impact on regional social welfare. The projects with the more negative EV values will have the greatest positive impact on social welfare and should then be given higher priority than projects with less negative EV values. Additionally, using a CGE framework, general economic benefits can be separated into sector-specific impacts, and changes in the distribution of wealth can also be analyzed.

The conceptual flow of activities in the CGE is relatively simple and straightforward. All firms in an economy produce their own unique goods from inputs (labor and capital) which are provided by the households. These goods, services, and commodities are then either utilized as inputs for other firms or consumed by households at the respective market clearing price. The underlying premise of all CGE models is the assumption that if all markets in a given economy are in equilibrium, then any individual market within that economy will also be in equilibrium and therefore a market clearing price and quantity exists for any individual sector of the economy.

In a CGE model, every sector in the economy is explicitly modeled along with its relationship to every other sector. This means that data is needed on production, consumption, and all inter-industry relationships associated with the factors of production (labor and capital) and consumption (earnings and payments). For the case of the Pacific Northwest, this is available from the 2010 IMPLAN data. For implementation of a CGE, Social Accounting Matrices (SAMs) representing all economic flows in an economy are generated within IMPLAN software and then exported to the Generalized Algebraic Modeling System (GAMS) for modeling.

Professors David Holland, Leroy Stodick and Stephan Devadoss have developed a regional CGE model using the GAMS programming language that has been used extensively for evaluating economic impacts from a host of policy changes. These include applications ranging from statewide economic impacts from mad-cow disease to impacts from tariffs on Canadian softwoods and the legislative mandated “Biofuel Economics and Policy for Washington State” study completed in 2010. For a detailed description of this model, including model closure, specified import demand functions, export supply functions, factor demand functions and household demand functions, please see http://www.agribusiness-mgmt.wsu.edu/Holland model/index.htm.

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