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Impacts of Ethanol Expansion on Cropping Patterns and Grain Flows*

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Abstract

Ethanol expansion has the prospect of having major impacts on cropping patterns and the spatial distribution of grain flows. These changes are in addition to those being driven by developments elsewhere in the world grain economy, including growth in consumption (e.g., China) and production in alternative regions such as Northern Brazil. This article develops a spatial optimization model based on longer-term competitive equilibrium to make projections about cropping patterns and grain shipments from individual ports. Most important among these trends are a shift in area toward corn and away from wheat, a reduction in corn exports, an increase in exports from competitor countries, and changes in domestic and international grain flows.

Key Words: Ethanol, Spatial Optimization, Grain Flows, Demand, Production

Impacts of Ethanol Expansion on Cropping Patterns and Grain Flows

Ethanol expansion has the prospect of having major impacts on cropping patterns and the spatial distribution of grain flows. Development of this industry is one of a number of structural changes in world grain trade that will impact the longer-term competitiveness of countries and regions. These changes are influenced by trends in consumption, which are impacted by tastes, and population and income growth. In addition, relative costs of production, interior and ocean shipping, and handling all have an impact on trade and competitiveness. With the rapid expansion of corn-based ethanol in the United States, in addition to these changes, there will be major changes in cropping patterns and grain flows. Interest in these and other factors impacting the longer-term evolution of world grain trade is particularly important for policy planners as it has implications for infrastructure investment and inter-country competitiveness.

The purpose of this article is to evaluate the impacts of developments in ethanol in the United States on cropping patterns and grain flows for three major grains: corn, soybeans, and wheat. We develop a spatial partial optimization model based on longer-run competitive equilibrium of the world grain trade using very detailed data and simulate changes in production and trade to the year 2040. In the first section, we provide background on changes in the ethanol sector. This is followed by a description of our model and data sources. Results are then presented along with forecasts. We then summarize and discuss the implications of ethanol developments on longer-term trade patterns.

Background on Ethanol

While there are numerous structural changes occurring in the world grain trade, developments in ethanol are particularly important. The increase in corn use for ethanol is an important change in

U.S. grain consumption. U.S. ethanol production has expanded rapidly over the last few years, from 1.63 billion gallons in 2000 to 4.86 billion gallons in 2006 (Renewable Fuels Association), and its rate of growth is expected to accelerate in the coming decade. The Energy Policy Act of 2005 established the Renewable Fuel Standards (RFS) at 4 billion gallons in 2006, increasing to 7.5 billion gallons by 2012. These increases will impact demand for domestic corn consumption in the future and decrease exportable supplies.

As the growth of the ethanol industry has accelerated, projections for ethanol production have changed. Both the U.S. Department of Energy, Energy Information Administration (EIA) 2005 and 2006 report projections to 2015. The EIA 2005 projected ethanol from corn production at just less than 4 billion gallons. The EIA 2006 estimates reflect current notions of ethanol production. In this case, ethanol production increases from 4 billion gallons to nearly 10 billion gallons in 2015 and then converges to about 12 billion gallons in 2020 forward. In the period after 2015, a minor portion of this will be met by ethanol from cellulose (U.S. Department of Energy, Energy Information Administration, 2005). These are fairly drastic changes. Demand growth should taper off beginning in about 2020. These levels of ethanol consumption suggest the growth in demand for corn for ethanol to increase from about 1.4 billion bushels in 2005/06 to about 4 billion bushels by 2020.

In our analysis, corn demand is split into that for ethanol and that for all other domestic consumption. Then, assumptions and transformations are used to derive ethanol demand by region. The location of new ethanol plants is an important aspect of this growing industry. Though ethanol production was earlier concentrated in the Eastern Corn Belt, the recent expansions have concentrated in the Western Corn Belt, which now has about 42% of the capacity. The Central Plains is the third largest region. Earlier plants located away from the

Mississippi River system, but a number of the more recent plants are located near the Mississippi River.

There are numerous issues and views on the prospects of there being enough corn to meet demands for both the growing world market and the U.S. ethanol market. The view that corn production can meet the demand for both is largely attributed to prospective advances in corn genetics increasing yield, along with some acreage increase. The National Corn Growers Association (NCGA) indicated that corn use for fuel will not take away from food, saying that this is "patently false and misguided, as US producers will continue to adequately supply all markets with high quality corn" (NCGA, p.4). Instead, their view is that the United States could produce 15 billion bushels of corn and 15 billion gallons of ethanol by 2015 (as reported by Zdrojewski). They indicated that historic yield trends would result in 162 bushels/acre by 2010 and 173 bushels/acre by 2015. Rob Fraley (Chief Technology Officer at Monsanto), indicated that doubling corn yields to 300 bushels/acre in 25 years was a reasonable goal (Sosland Publishing). New technology includes traits influencing yields, drought tolerance, fertilizer use and pest resistance. With these advances, he indicated it would be possible to increase ethanol production to 50 billion gallons, based on a corn crop of 25 billion bushels from 90 million acres in 2030. Producers have responded to the increased demand for corn for ethanol by increasing corn plantings to 93 million acres in 2007, up from 78 million acres in 2006 and the highest total since 1944. The increased acres have mostly come from a reduction in soybeans.

Additional corn acres could come from the Conservation Reserve Program (CRP). The role of CRP in expanding area available for planting is a major policy issue. For perspective, there are 36 million acres in CRP. In 2007 there were 16 million acres scheduled to come out. USDA had earlier offered re-enrollments of these acres. By mid-November, higher prices were not enticing landowners to move land back into production and USDA was expecting an 81% retention rate. There are 3 million acres in CRP that would be available for 2008, and the USDA has made offers for CRP contracts expiring in 2008-2010 totaling 12 million acres. Preliminary estimates are that only 15% would be accepted (Kovers).

The ability to release area from CRP for this purpose is not as easy as posed. Fatka indicated the industry was looking for 4-8 million acres of corn for next growing season. Mann Global Research (2006b) reported that the trade is fully aware that up to 3 million CRP acres could be available in 2007. However, they noted that this CRP land is of questionable agricultural value, with the greatest amounts in Texas, Kansas and North Dakota. Some of this could be switched into wheat, but corn would be unlikely. The crop land coming out of production in the Corn Belt is limited, with Minnesota and Iowa at about 300,000-500,000 acres. Though USDA had hinted that a plan has been formulated to increase the amount of acres from the CRP, any further details were merely speculation. While farmers with CRP could opt out of the contracts, they would incur penalties to do so (Pates). Specifically, though there are ideas of early opt-outs, this is unlikely without a change in the rules. Under exiting rules, anyone wanting to opt out of a CRP contract would have to pay back all the money they had received in that contract, plus liquidated damages, a penalty equal to 25% of one annual payment, amongst other costs. Taken together, it is unlikely that much CRP area would be returned to production without a change in the rules.

A recent study modeled the potential impacts of ethanol on corn production and international trade (Elobeid, et al.). Their results indicated that the break-even feedstock corn price would be $4.05/bushel and that at this price, corn-based ethanol would increase to 31.5 billion gallons by 2015. To support this industry, the United States would have to plant 95.6

million acres of corn and produce 15.6 billion bushels (up from 10.5 billion bushels in 2006). Most of the acres would come from reduced soybean acreage. Corn exports would be reduced substantially, and the study even suggested the United States could become a corn importer. There would be a 9 million-acre reduction in soybean area and a change in rotation from corn-soybean to corn-corn-soybean. Wheat exports would decline 16%.

ProExporter (2006b), in their *Blue Sky* model, indicated a permanent shift in corn prices to the $3.50-$4.00/bushel area into at least 2015. They suggested there would be origination wars in Minnesota, Iowa and Nebraska as shuttle shippers for feed to California and the Southwest, and the Pacific Northwest (PNW) would have to compete with ethanol plants in procuring corn shipments. However, due to superior margins in ethanol, the latter would set the price and force others to pay more. Stocks would be drawn down, exports would decline, and there would be greater volatility in prices and supplies.

Many of these issues revolve around assumptions on future supply and demand (e.g., as done by one of the more respected analysts in this area, ProExporter (2006a)). Assumptions about increased yields, increased conversions from corn to ethanol, and increased area planted to corn are all critical to these analyses. With adjustments in these values, by drawing down stocks, and assuming no risk or crop shortfalls, one can demonstrate there would be adequate supplies to meet the increased demand for ethanol, though, typically, exports decline.

Empirical Model

To analyze competition and future trade implications, a large-scale spatial partial optimization model of world trade in grains is developed. The model is not described here due to its volume. It is summarized and a detailed representation is provided in the appendix to this paper. The model, along with the data inputs and transformations and more detailed results are available at (Wilson, et al., 2006).

Briefly, the objective of the model is to minimize production costs of grains and oilseeds in major producing countries and marketing costs from producing regions to consuming regions, subject to meeting import demands at importing countries and regions, available supplies, production potential in each of the exporting countries and regions, and shipping costs and technologies. The model includes agricultural production and export subsidies, import tariffs, and other trade measures that may affect international competition.

The logic to the objective function is that it reflects what would be considered a longer-term competitive equilibrium whereby spatial flows are determined by costs, technical restrictions, and other relationships. Under these conditions, trade flows of agricultural commodities would be determined by demand, production and marketing costs in exporting countries, and trade interventions. Demand is projected and the least cost means of meeting that demand is derived. This differs from econometric models that use functional relationships to project equilibrium trade levels. Such models are generally incapable of capturing spatial elements of competition. Given our objective is to make longer-term forecasts, and the greater emphasis is on spatial and modal distributions, a model based on longer-term competitive equilibrium is developed. However, this class of models is not without problems. Most important is that there is no direct link between the grain sector and the rest of the economy. There are indirect links between consumption and population and income and between production costs and exchange rates. However, these are not directly linked in the model. As a result, this is a partial spatial optimization model and subject to these restrictions.

The model is solved jointly for corn, soybeans, and wheat. Costs included in the model are direct production costs for each grain in each exporting country and region less production subsidies, interior shipping and handling costs for each grain in each exporting region less export subsidies, and ocean shipping costs plus import tariffs. Transportation modes include truck, rail, and barge for inland transportation and ocean vessel for ocean transportation. The model includes six segments on the U.S. river system, commonly called reaches. Four of the six reaches have delay functions that reflect congestion costs which are an added cost to barge shipping.

The objective function is solved using nonlinear (due to nonlinear costs) optimization subject to a set of constraints, including arable land constraints in exporting countries and demand constraints for each type of grain and oilseed in consuming regions of exporting and importing countries. In addition to the restrictions stated above, some selected restrictions are imposed on the model to calibrate it to current trade patterns.

The model is ultimately used to make projections. To do so, the following logic is used. Demand is projected for each country and region based on income and population projections from *Global Insights* (2004a). Yield and production costs for each producing region are derived. Production potential is determined in each country/region subject to the area restriction. Modal rates are derived for the base period. Ocean shipping cost projections are based on oil prices, a number of other exogenous and geographic variables, and trend. Using these estimates, the model is solved for each year in the projection horizon. The model determines quantity produced in each country and region, import demand, and trade flows from origins to destinations. The model is defined in GAMS and includes 12,979 variables and 742 constraints.

Base Case Definition

The base case uses data for the 2000-2004 period and its results are compared to those from alternative scenarios. Table 1 defines the major assumptions for the base period and projection period. Crop land in the United States is restricted to 100% of the historical area harvested, and yields are based on longer-term trends. These assumptions are retained in the projection period, but both are relaxed as sensitivity analysis is conducted. Ethanol use of corn in the United States is assumed at the EIA 2005 projections, and sensitivity analysis is conducted to allow for increased ethanol use as projected by EIA 2006. The unrestricted model provides a longer-run solution which would likely be less appropriate for comparing the shorter-run results in particular years.

Results

The base case model is calibrated relative to the average trade and modal flows during the period 2000-2004, a recent period of relatively stability. Model results are compared first at the world trade level, then at U.S. ports. In each case, model results are compared to actual results over the base period. The model performs well in replicating the total quantity of exports from the United States as well as most competitor countries (table 2). Total U.S. exports in the base period are 101 million metric tons (mmt), consisting of 44 mmt, 30 mmt, and 27 mmt of corn, soybeans, and wheat, respectively. World trade in these grains is 83 mmt, 61 mmt, and 119 mmt, respectively, for a total of 264 mmt. Results from the model are very comparable to actual shipments. Export volumes from the United States are comparable by grain type, as are inter-port exports. The exception is East Coast exports, which should be sightly greater than that generated from the model. Otherwise, inter-port shipments are very comparable.

Projections

The model is used to make projections for production, trade flows, and exports by ports (as well as internal shipments). A critical assumption is made that restricts China's exports to 8 mmt in the base period, and thereafter their exports and imports are restricted to nil.

In some cases it is necessary to make adjustments to the maximum area allowed to be planted in order get a solution, i.e., this is due to supplies being less than demand at the world level. To do this, we retain the base case assumptions, and then make adjustments until a solution is attained. The area restrictions are interpreted as a percentage of base total projected area, which varies through time (see model overview). For some countries there have been gradual reductions in area planted (e.g., U.S., EU and China) whereas in others there have been increases (e.g., Argentina and Brazil). The percentage adjustment is made relative to that projected area and in all cases is treated as a maximum restriction. For the United States, this value is 107%. Strict interpretation of this is that in order to produce adequate supplies to meet demand, the area devoted to these crops in the rest of the world would have to increase by these values.

Results indicate that U.S. exports increase from 101 mmt to a peak of 122 mmt in 2010 and then decline (table 2 and figure 1). As U.S. exports stagnate or decline, world trade continues to grow, causing a shift in trade patterns. Total world trade increases from 264 mmt to nearly 406 mmt in 2040. Total exports increase substantially from Argentina (29 mmt to 44 mmt) and Brazil (21 mmt to 47 mmt), as well as Europe and Australia. There are notable increases in exports of corn and soybeans from Argentina; wheat from Australia; corn and wheat from Europe, which includes Eastern Europe; and soybeans from Brazil. Most of the increased soybean exports are from Brazil and Argentina, as shipments from these two countries increase from 20 mmt and 9 mmt, respectively, to 43 mmt and 19 mmt, respectively, by 2040. Wheat exports from Argentina, on the other hand, declines substantially after 2030. Thus, the shift is for increased corn from Argentina and Eastern Europe, soybeans from Brazil and Argentina, and wheat from Australia, Canada, and Europe; and reduced wheat from Argentina and the United

States.

The increase in U.S. exports from the base period to 2010 is due in part to the assumption that the maximum area for plantings would increase to 107% and in part due to reductions in China's corn exports from 8 mmt to nil in 2010. This result implies less CRP land (as represented by the 7% increase in area planted) and/or taking area from other crops (i.e., other than corn, soybeans, and wheat). After peaking in 2010, U.S. exports, which are concentrated in the U.S. Gulf (including the Texas Gulf), decline to 91 mmt by 2040 (Figure 1). Exports from the PNW decline from 25 mmt to 16 mmt in 2040. U.S. corn exports decline the most, from a peak of 62 mmt to 42 mmt. Wheat exports also decline substantially, but soybean exports increase slightly. The decline in U.S. exports that occurs after 2010 is in part due to increased competitiveness of other exporting countries and increased domestic use of these crops (notably for ethanol). Ethanol consumes an increasing amount of corn and leads to a shift in area planted amongst these crops. Most important is an increase in corn area planted, and soybean acreage increases as well. These increases are offset by reductions in wheat area.

There are also significant changes in cropping patterns around the world. Corn and soybean acres increase worldwide to meet the demand for these crops, and wheat acres decrease. Notable among these changes, beside the shift in U.S. acres, is an increase in corn acres in Mexico, South Asia, and Southern Africa; an increase in soybean acres in Argentina, Brazil, China, and South Asia; and a general decrease in wheat acres in a number of countries, with the exception of Australia and Northern Africa, where acreage increases.

Finally, the results illustrate that the United States remains an important exporter of soybeans, which is due to it being a low-cost producer and global demand growth being strong throughout the forecast period. Brazil's exports grow by a greater amount due to it having a larger amount of land to bring into production than the other soybean producers. Thus, the United States retains its soybean production to the extent it is technically feasible (including substituting acres for corn, etc.) and exports the remainder. As the world needs more soybeans, it attracts that by increasing area devoted to the crop, primarily in northern Brazil, even though production in this region is at a higher cost.

For comparison, and to illustrate the importance of U.S. area restrictions, we ran the model for 2010 assuming the maximum area was 100%, as opposed to 107% shown here. The impacts of this are to shift area and exports to other countries, as expected. From a port perspective, the PNW shipments decline from 18 mmt to 9 mmt; and those through the U.S. Gulf decline from 92 mmt to 72 mmt.

Ethanol Scenarios

The emergence of ethanol is a major change in U.S. grain agriculture. Base case projections allow expanded ethanol demand for corn in the United States based on EIA 2005 projections. Since these projections were made, the Energy Policy Act of 2005 was signed, resulting in a prospectively greater amount of ethanol produced. To explore the prospective impacts of further changes in ethanol, a scenario is run assuming the EIA 2006 estimates of ethanol produced from corn. In this case, ethanol production increases from 4 billion gallons to nearly 10 billion gallons in 2015 and then converges to about 11 billion gallons for 2020 forward. All other assumptions from above are retained. For comparison, ProExporter's (ProExporter 2006b) "Blue Sky" model has ethanol growing to 18.7 billion gallons by 2015/2016.

Results indicate that the increased ethanol production leads to changes in production and exports amongst exporting countries and regions. World exports from these countries decrease slightly, suggesting there is increased domestic production in some importing countries. In particular, world trade in 2020 declines from 318 mmt in our base case to 296 mmt. Compared to the base case projections for 2020, the high ethanol scenario projections for 2020 show increases in corn exports from Argentina (16 mmt to 18.5 mmt) and Europe (36 mmt to 46 mmt); a decrease in soybean exports from Brazil (25 mmt to 23 mmt), in part due to a shift to corn in southern Brazil; increases in wheat exports from Australia (29 mmt to 32 mmt) and marginally from Canada; and decreases in wheat exports from Europe (41 mmt to 31 mmt) and the United States (20 mmt to 19 mmt). In this scenario there are further increases in corn acres worldwide, notably in Brazil and Europe. The reason for the rapid growth in corn in Europe, including Eastern Europe as we define these regions, though, is mostly due to yield growth, which over the projection period is far greater than that for the rest of the world (i.e., yields increase from 6.16 mt/ha to 13.39 mt/ha over the projection period). This is a statistical result and is due to technology in that region catching up with the Rest of the World.

Harvested area for corn, soybeans, and wheat in the United States is essentially the same in this scenario as in the base case, though soybean acres are slightly lower. However, there is a significant drop in exports. Exports from the United States under high ethanol demand decline from 101 mmt in the base year to 78 mmt by 2020, compared to the base case where exports increase over the same period to 111 mmt (figure 2). Gulf and PNW exports in 2020 decrease to 51 mmt and 15 mmt, respectively, with high ethanol demand, compared to the base case projections of 76 mmt and 23 mmt, respectively. Changes in exports in this scenario are due almost entirely to a substantial drop in corn exports. U.S. corn exports decline to zero by 2030 in this scenario. As U.S. corn exports fall, those from Argentina and Brazil increase (figure 2). Corn exports from Argentina and Brazil for 2040 increase from 23 mmt and 4 mmt, respectively, in the base case to 27 mmt and 12 mmt, respectively, under high ethanol demand. U.S. wheat exports also decrease significantly, but the decline is only slightly greater than what occurs in the base scenario. Soybean exports are also slightly lower in the high ethanol scenario compared to the base case.

Within the United States, grain flows in the high-ethanol scenario change substantially in 2010 . Most interesting is the drastic increase in shipments to the Eastern and Western corn belts, reflecting the increase in domestic demand for ethanol use.[1] Also of interest are changes in flows from the Northern Plains, which had previously exported most of its corn through the PNW. A substantial portion of these shipments is now shifted to domestic destinations. Shipments from the Northern Plains to the PNW decline from 14 mmt to 6 mmt.

There are substantial changes in flows from U.S. production regions to the Reaches and port areas. Most important is the reduction in shipments from Iowa, Minnesota, and Illinois to the river. Finally, there are reductions in shipments from most regions to New Orleans.

The impacts of increased ethanol demand on U.S. exports are summarized in figure 3. Three scenarios for ethanol demand are shown here. These include the base case; the high ethanol case, which implies ethanol production of 12 billion gallons; and an additional scenario, mid ethanol, which illustrates the impacts of 7.5 billion gallons of ethanol. In the high ethanol case, exports decline sharply, eventually to 38 mmt. Corn exports fall to 0 by 2030. Soybean exports increase until about 2030 and then the combination of competition from corn in the United States and off-shore increases in production results in reduced barge exports. Finally, wheat exports decline from 27 mmt to 12-14 mmt in all cases by 2040.

Qualifications and Stylized Assumptions on the High-ethanol Scenario

The high ethanol scenario is posed for illustration, in part because of the overriding importance of ethanol in the U.S. grain economy and also because of the importance of these developments on the barge system. If EIA 2006 demand were to be realized, and corresponding with the spatial distribution of current ethanol plants, the model needs to make some extreme assumptions in order to get a solution. In particular, it requires expanding U.S. acres by 7%, reflecting approximate land available in CRP, and, in addition, increasing area available elsewhere in the world. Our base case also has China's exports at nil. All these topics are debatable. Most important are those related to yield increases, the ability to expand area in the United States, and demand for corn for non-ethanol purposes. If corn prices increase, demand in some segments within the United States and/or off-shore would be impacted. These impacts, of course, would change the potential grain flows as generated from this scenario.

In order to evaluate the assumptions about these critical variables, we simulated the model with alternative assumptions with respect to yields and acreage for the year 2020. Yields in 2020 are increased 5% and corn area harvested is increased from 67 million acres to 88 million. This implies that 97 million acres are allowed to be planted to corn, a 32% increase from the base. These values are at the national level and are implemented in the model as proportionate changes by region. The land area for soybeans and wheat are reduced so that the maximum land for these three commodities is unchanged. However, ultimately the model chooses which crops are grown and where, so these changes reflect maximums allowed and may not be fully utilized. These analyses are representative of some of those that have been posed to assess the impacts of ethanol. Changing these assumptions has the impact of increasing U.S. supplies of corn. Most important is that the model requires reconciling shifts in acres relative to the competing crops (corn, soybeans and wheat) in the United States as well as competitor countries.

The results from this scenario for exports from the United States, Brazil, and Argentina are compared in Figure 4 to those from the original high ethanol scenario for 2010 and 2020. Results from the revised assumptions are labeled as "Revised 2020." Most striking is that total exports from the United States increase rather than decrease. Total exports are 129 mmt in 2020, and exports from the U.S. Gulf and PNW are 86 mmt and 29 mmt, respectively. Corn exports from the United States increase to nearly 83 mmt in 2020, as opposed to declining to 26 mmt under the base high ethanol demand scenario. In the revised 2020 solution, corn exports decrease from Argentina and Brazil. Soybean exports from the United States decline more significantly in this scenario, from 36 mmt in 2010 to 28 mmt in 2020, while those from Brazil increase sharply, from 23 mmt in 2020 in the original high ethanol scenario to 32 mmt in the revised case. Wheat exports increase from each of the competitors, and those from the United States decline, but the change from the original high ethanol scenario is minor. These changes are interesting, and they illustrate that minor tweaking of assumptions results in fairly important changes. Our results suggest increased corn acres would come mostly from wheat, CRP, and/or from other minor crops not included in the model. Some could come from soybeans, but there are substantial international competitive pressures and demand for the United States to retain its soybean area.

Conservation Reserve Program (CRP)

One of the more important U.S. policies in the near term that could impact these results is the administration of the CRP program. The CRP is a program to protect environmentally sensitive lands. In 1998, 18.5 million acres were put under the program. Currently, there are 36 million acres in this program. These acres are mostly concentrated in the dry sections of the Great Plains, with 16.4 million acres in Texas, Montana, North Dakota, Kansas and Colorado.

There are minor amounts of CRP land in the corn belt states, including 2 million in Iowa and 1.1 million in Illinois. Most of these acres are not up for renewal anytime soon. Of the 16 million acres coming up for renewal in 2007, 3 million acres are currently slated to expire and not re-enter the program. The bulk of these are in the plains, with just 114,000 acres expiring in Iowa and 70,000 acres in Illinois.

These values represent 7% of the land in the model's base period. If prices are strong during the expiration period, a portion of these acres may be returned to production. During late 2006 there was discussion that USDA would announce a more meaningful shift in the CRP system that will have a big impact over the coming decade (as reported by Mann Global Research, 2006a, amongst others). There was an idea that USDA would enact policies to substantially increase U.S. corn planting, beginning in 2007 and then expanding dramatically over the coming decade. While this will presumably be a several point plan, the crux will center around returning CRP acreage to production and a corresponding shift into grain and oilseed crops. These discussions were subsequently characterized by Secretary of Agriculture Johanns as baseless, but the issues remain hotly debated (Tomson).

To assess the importance of using CRP land, the model was used to evaluate the impacts from returning it to production. Results are not repeated here since a maintained assumption was that the maximum area would increase by 7%, commencing with the 2010 projection. The result of our base case projections implies a return of these acres to production. As noted above, if these were not returned to production, the result would be that competitor countries expand their area.

To explore this further, the model is run for 2020 assuming an additional 7% increase in area available for planting where this 7% is allocated based on the distribution of CRP acres by production region. The results, shown in Figure 5, illustrate that if this were to occur, U.S. exports would increase from 111 mmt to 132 mmt, and exports from competitor countries, including Brazil and Argentina, would decline. U.S. corn exports would increase the most (13 mmt) split nearly evenly between increases in Gulf and PNW exports. Wheat exports from the Gulf would increase 5 mmt. Soybean exports would decline from the Gulf but increase from the East Coast and PNW, resulting in a 2 mmt increase overall.

Summary and Conclusions

The purpose of this article is to evaluate the impacts of developments in ethanol in the United States on world cropping patterns and trade for three major grains: corn, soybeans, and wheat. We develop a spatial partial optimization model based on longer-run competitive equilibrium of the world grain trade using very detailed data and simulate changes in production and trade to the year 2040. The competitiveness of the U.S. agriculture sector is emphasized, impacts of critical variables on U.S. competitiveness are assessed, and changes in flows are projected.

Using a spatial optimization model of world grain trade, important parameters are forecasted and used to evaluate changes in flows through specific logistical channels. Projected import demands are based on consumption functions, which are estimated using income and population and account for inter-country differences in consumption dependent on economic development. Each of the competing supply regions and countries are represented by yields, potential production area, costs of production, and interior shipping costs where relevant. Crucial in this model is the interior spatial competition between the U.S. Pacific Northwest and shipments through the U.S. Gulf, as well as inter-Reach competition on the river system. This differs from other analysis based on econometric projections which do not address inter-port and inter-Reach competition. This model differs from others in additional ways. First, it includes shipping and handling costs. Second, it is a longer-run model. Consequently, the model allows for numerous longer-run adjustments. Thus, the comparative statics capture the impact of longer-run adjustments. The model has very extensive inter-modal competition which affects inter-port, inter-reach, and inter-regional competition.

The results identify a number of important factors that will impact production and distribution of these agricultural commodities. The explosion of the ethanol industry will have an important impact on the amount of corn available for export. In concept, U.S. energy policy will result in increased domestic demand for corn, increased planting of corn to the extent technically possible, and reduced plantings of wheat in the United States. The latter will result in increased plantings in other countries and reduced exportable supplies from the United States.

The results suggest that after 2010, U.S. corn exports decline the most, from a potential peak of 62 mmt to around 42 mmt. Wheat exports also decline substantially, but soybeans increase through 2030. Exports from the U.S. Gulf decline to 63 mmt in 2040 after reaching a peak of 92 mmt in 2010. Exports from the PNW total 25 mmt in the base year and decline in later years. The results indicate that the United States remains an important exporter of soybeans.

The base case assumes EIA 2005 projections of corn use in ethanol demand, and then the model is revised to assume the higher EIA 2006 estimates. As a result of this increase in corn used for ethanol, exports from the United States decline to 78 mmt by 2020, compared to the base case projection of 111 mmt in 2020. Gulf exports decrease (65 mmt to 51 mmt) and PNW exports fall to 14 mmt. Most of the decline is in corn shipments. Soybean exports remain at about 30 mmt. Exports from Argentina, Europe and Eastern Europe increase as well as wheat exports from Australia.

In addition, there are major changes in flows within the United States. Most interesting is the increase in shipments to the Eastern and Western corn belts, reflecting the increase in domestic demand for ethanol use. Most of the corn from the Northern Plains was previously exported through the PNW, but now a significant portion is shipped to domestic destinations. There are also substantial changes in flows from U.S. domestic regions to the Reaches and port areas. There are reductions in shipments from Iowa, Minnesota, and northern Illinois to the river, and there are reductions in movements from most regions to New Orleans, except for an increase from southern Illinois.

Finally, the model is run assuming more stylized assumptions for some critical variables, mostly impacting the ability of corn production to expand to meet these competing demands. The results suggest the model is fairly robust in capturing these different assumptions. When the model is revised to allow for a greater expansion of corn production: 1) corn exports from the United States increase substantially; 2) soybean exports from the United States decline, while those from Brazil and Argentina increase sharply compared to our base case solution; 3) wheat exports increase from each of the competitors and those from the United States decline slightly; and 4) reach shipments decline, but not as drastically. The results of the sensitivity analysis illustrate that changing assumptions on variables such as yield growth and the ability to expand corn acres has a significant effect on the outcome.

One of the more important U.S. policies in the near term that could impact these results is the administration of the CRP program. The model is used to evaluate these impacts. Results are reflected in the base case projections since returning 7% of the base area is a maintained assumption. If these CRP acres are not returned, competitor countries would expand production and export demand would decline by 10 mmt. In either case, this is a critical policy that impacts exports and shipping demand.

Footnotes

1) Detailed matrixes of domestic and international shipments under these scenarios are in Wilson et al., 2007.

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Table 1 Base case assumptions

Model Assumption	Base Period 2000-2004	Projection Period	Sensitivities during projection period
Barge system capacity	Barge rate functions and delay curves by reach	Existing capacity	
Non-Grain Barge	2000-2004 average levels	Assumed same as base case	
US rail car capacity	Restricted rail capacity		
Modal rates	Rail from 2000-2004 average; barge rates represented as rate functions by Reach; ocean rates derived from a regression	Assumed same as based case	

US area restrictions	3 restrictions imposed:
	minimum total area=100% of recent 3 year average;
	maximum total area=100% of base;
	maximum area that can be switched among crops was 7% from the base period.
		Maximum changed to 107% in 2010 forward	Relaxed to allow expanded production as required

Rest of World (ROW) area restrictions	3 restrictions imposed: minimum total area=100% of recent 3 year average; and minimum area for any one crop=88% of base; maximum total area=107% of base; maximum area that can be switched among crops was 7% from the base period.	Maximum changed to 107% in 2010 107% in 2020 115% in 2030 115% in 2040 121% in 2060	
Ethanol production	U.S. Department of Energy, EIA 2005 projections	EIA 2005 projections	EIA 2006 Projections
China corn trade	Exports subsidized to 8 mmt	China exports=0	
Other Trade policies	Retained		

Table 2. Exports by selected countries and port areas by crop (thousand metric tons)

Total	Base Period	2010	2020	2030	2040
Argentina	28,962	24,197	35,799	50,572	44,026
Australia	19,817	22,376	28,701	39,964	33,575
Brazil	21,051	19,785	26,801	31,272	46,979
Canada	12,424	13,164	12,287	15,168	17,509
China	8,000	0	0	0	0
Europe-E. Europe	44,631	59,570	77,081	108,641	139,491
US EC	2,554	2,580	2,613	2,147	2,147
US Gulf	65,215	91,864	75,889	62,214	63,176
US PNW	24,594	18,178	22,639	16,388	16,242
US Mex Dir	8,234	9,097	9,915	11,074	9,442
U.S. Total	100,597	121,719	111,056	91,823	91,008
World Total	263,899	282,477	317,886	370,838	406,325
Corn					
Argentina	11,122	10,172	16,060	21,033	22,818
Australia	17	0	131	270	360
Brazil	1,432	1,675	1,460	3,822	3,589
Canada	0	0	0	0	0
China	8,000	0	0	0	0
Europe-E. Europe	19,000	21,322	36,027	56,105	64,649
US EC	0	0	0	0	0
US Gulf	32,767	53,160	48,485	38,863	42,600
US PNW	9,923	8,886	7,111	646	1,589
US Mex Dir	1,005	315	0	0	379
U.S. Total	43,695	62,361	55,596	39,509	44,568
World Total	83,266	95,529	110,897	125,955	142,777
Soybeans					
Argentina	7,997	5,914	9,710	17,644	19,318
Australia	0	0	0	0	4
Brazil	19,620	18,110	25,341	27,451	43,389
Canada	0	0	0	0	0
China	0	0	0	0	0
Europe-E. Europe	0	0	0	0	0
US EC	0	0	0	0	0
US Gulf	19,924	28,524	22,697	23,351	20,577
US PNW	6,101	1,670	7,906	8,120	7,031
US Mex Dir	3,995	4,685	5,000	5,000	4,621
U.S. Total	30,020	34,879	35,603	36,471	32,229
World Total	61,333	63,544	74,676	89,173	100,125
Wheat					
Argentina	9,842	8,112	10,029	11,895	1,890
Australia	19,799	22,376	28,570	39,694	33,210
Brazil	0	0	0	0	0
Canada	12,424	13,164	12,287	15,168	17,509
China	0	0	0	0	0
Europe-E. Europe	25,630	38,248	41,055	52,536	74,843
US EC	2,554	2,580	2,613	2,147	2,147
US Gulf	12,524	10,181	4,707	0	0
US PNW	8,570	7,622	7,622	7,622	7,622
US Mex Dir	3,234	4,097	4,915	6,074	4,442
U.S. Total	26,882	24,479	19,858	15,843	14,211
World Total	119,299	123,404	132,312	155,711	163,423

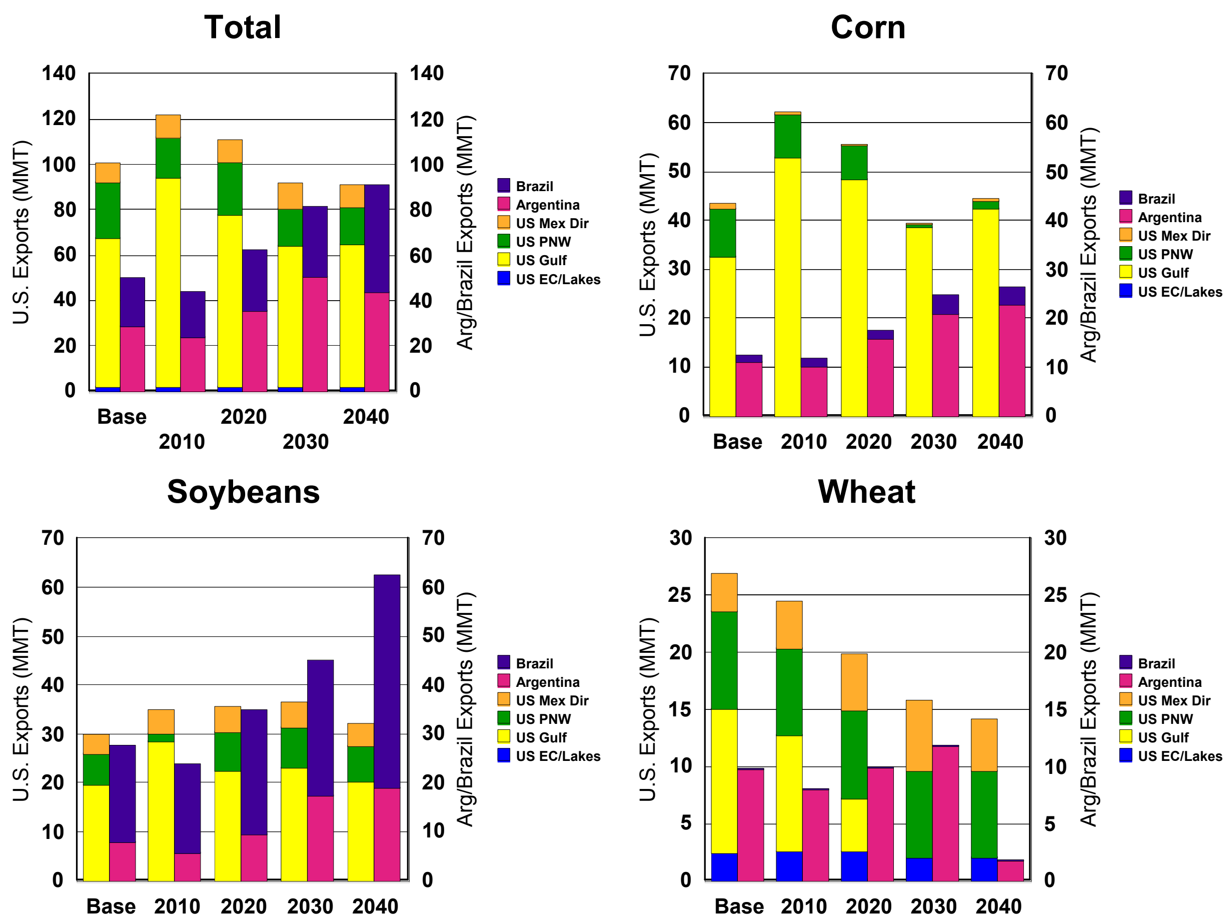

Figure 1. Base case projections: U.S. exports by port area and exports for Argentina and Brazil.

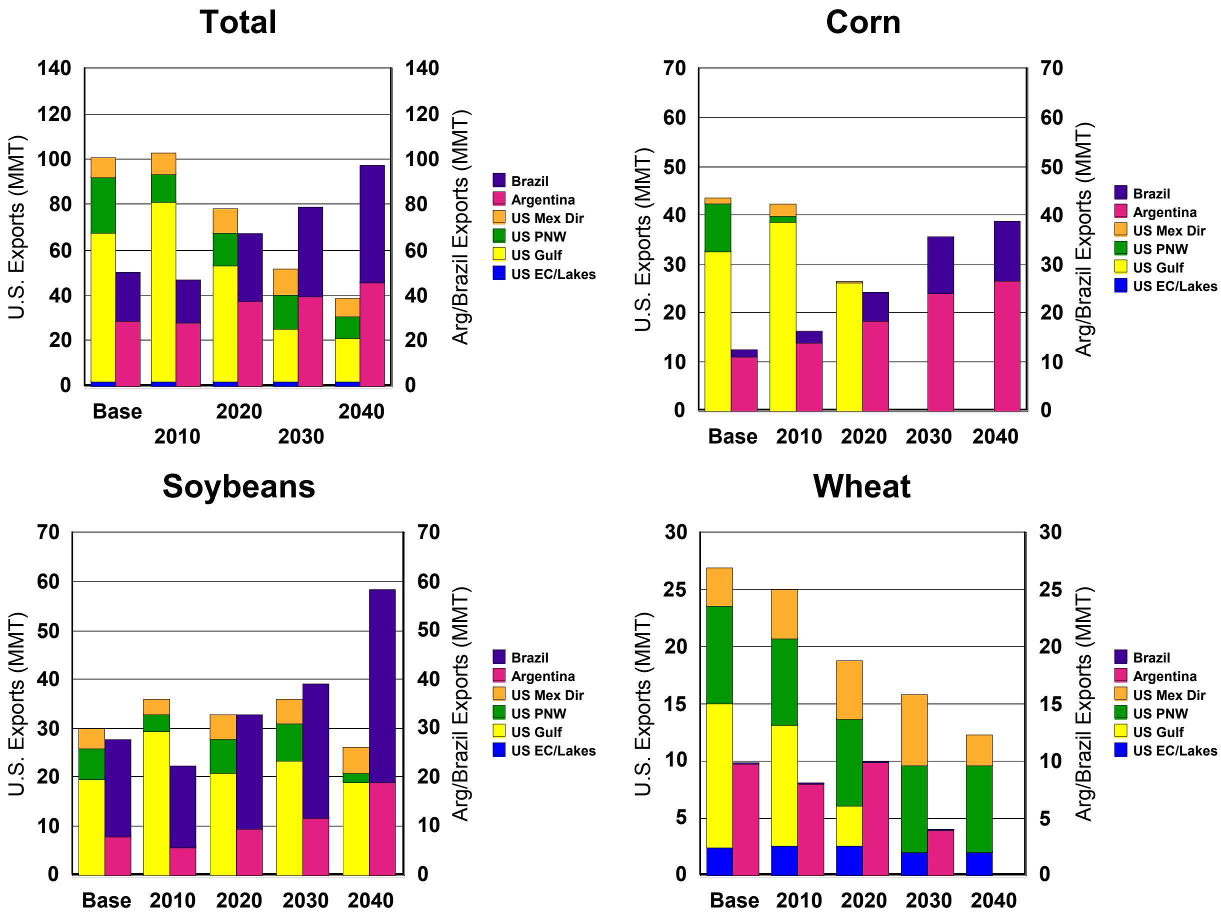

Figure 2. High ethanol demand scenario: U.S. exports by port area and exports for Argentina and Brazil.

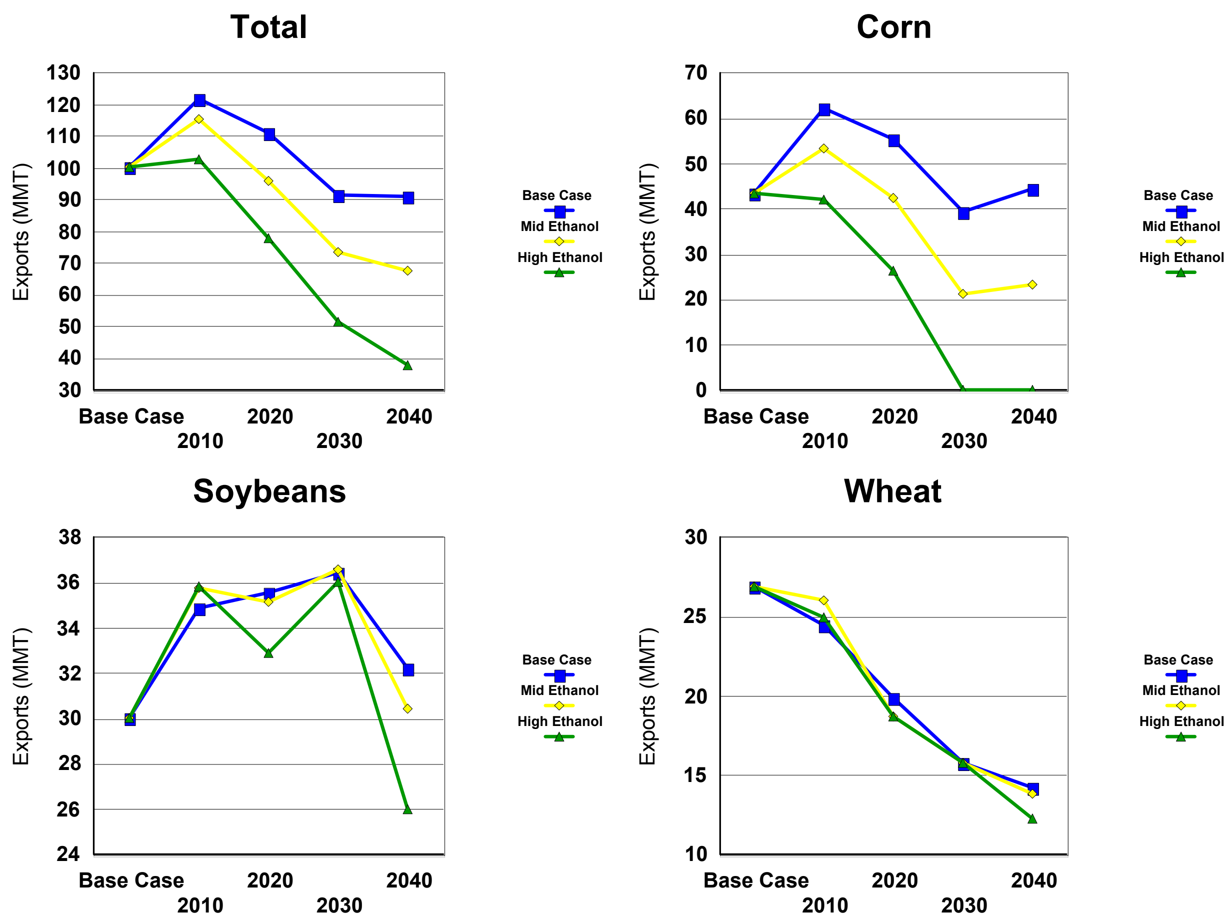

Figure 3. Comparison of U.S. export volumes for ethanol scenarios, base case, mid ethanol and high ethanol demand scenarios, by crop and total.

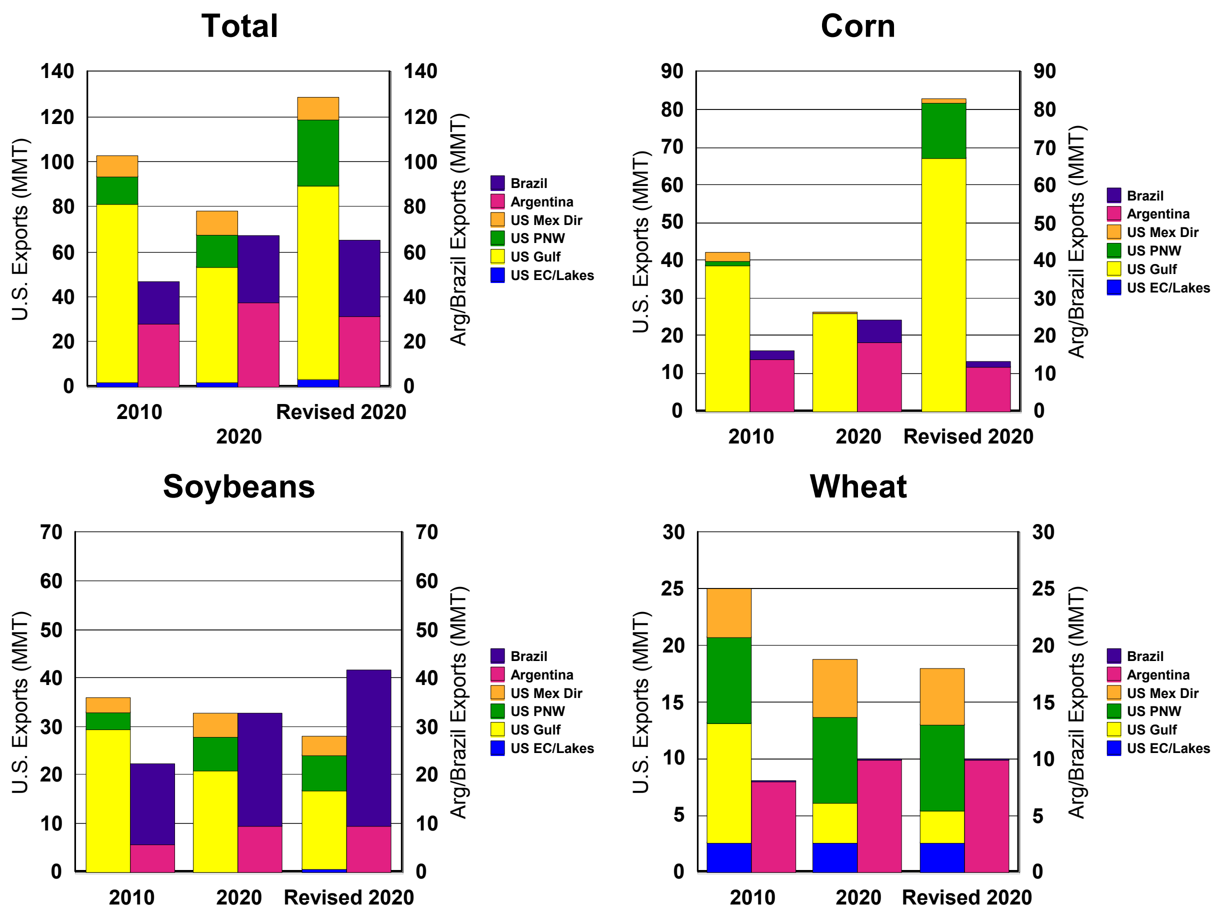

Figure 4. **Comparison of U.S. exports by port area and exports for Argentina and Brazil for high ethanol 2010 and 2020 with revised 2020 scenario, by crop and total.**

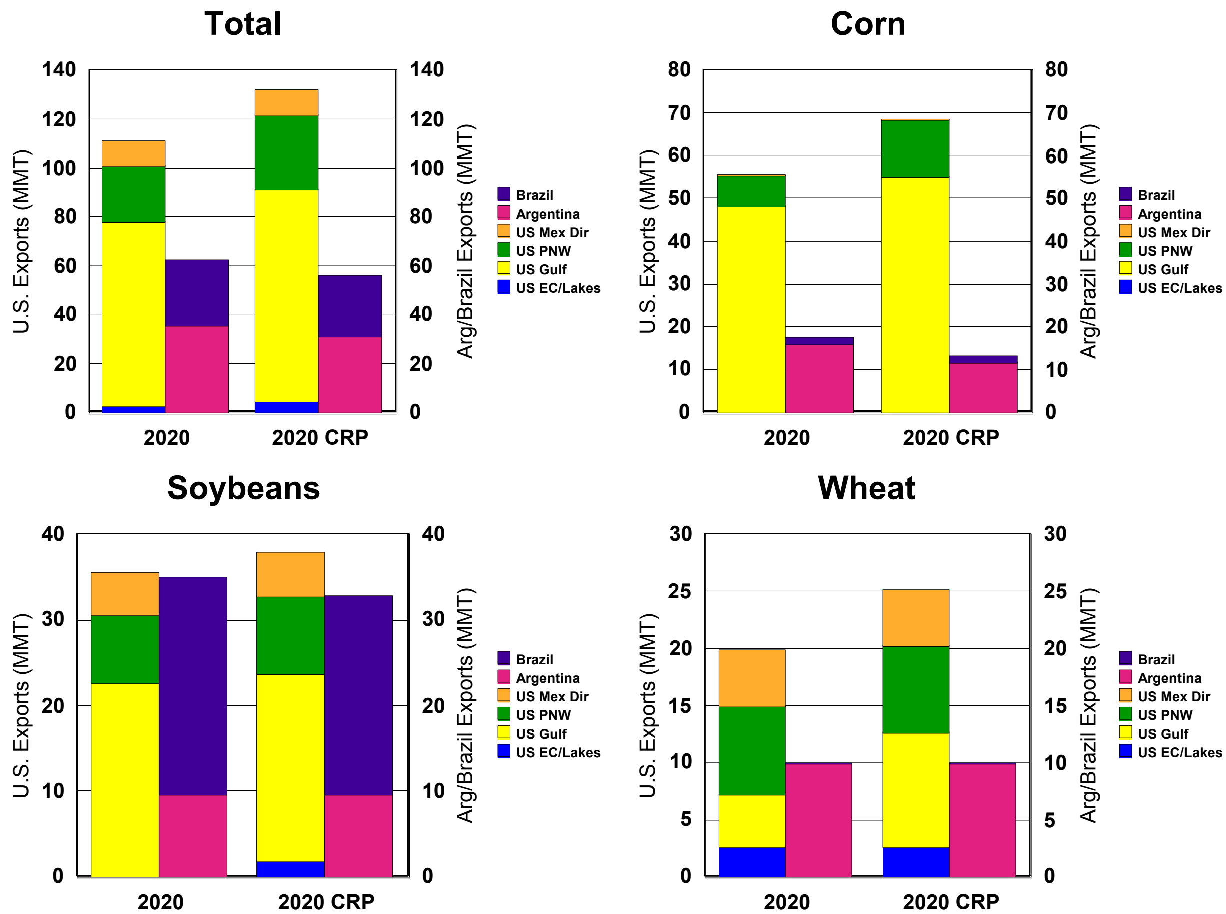

Figure 5. Argentina, Brazil and U.S. exports by port area, 2020 and 2030 with additional CRP area.

Appendix A: Detailed Summary of the Model Specification and Data

A large-scale, non-linear spatial optimization model is used to make projections and analyze delay costs. This is a very detailed and comprehensive model. This appendix provides an overview of the procedures and the specification of the analytical model. Agronomic and consumption were estimated econometrically and are described first. Then, we describe the spatial optimization model and data sources.

Spatial Optimization Model

The objective of the model is to minimize production costs in producing regions in exporting countries and shipping costs from producing regions in exporting countries to their consuming regions and importing countries. This objective function is defined as:

$$
\begin{aligned}
W = & \sum_{c}\sum_{i}(PC_{ci} - s_i)A_{ci} + \sum_{c}\sum_{i}\sum_{j} t_{cij}Q^{t}{}_{cij} \\
& + \sum_{c}\sum_{i}\sum_{w} t^{R}{}_{cij}Q^{R}{}_{cij} + \sum_{c}\sum_{i}\sum_{w} t^{t}{}_{ciw}Q^{t}{}_{ciw} \\
& \sum_{c}\sum_{i}\sum_{p} t_{cip}Q^{R}{}_{cip} + \sum_{i}\sum_{w}\sum_{p}(t_{cwp} + B_p)Q^{B}_{cwp} \\
& + \sum_{c}\sum_{p}\sum_{q}(t_{cpq} + r_q)Q_{cpq}
\end{aligned}
$$

where *i*=index for producing regions, *j*=index for consuming regions, *p*=index for ports in exporting countries, *q*=index for ports in importing countries, *w*=index for river access point on the Mississippi River System, *B*=barge, *R*=rail, *T*=truck, PC_{ci}=production cost of crop *c* in producing region *i*, A_{ci}=area used to produce crop *c* in producing region *i*, *t*=transportation cost per ton, *Q*=quantity of grains and oilseed shipped, *S*=production subsidies in the exporting country; *r*=import tariffs in the importing country; and *B*=delay costs associated with barge shipments on each of four reaches on the Mississippi River.

The first term on the right-hand side represents production costs in producing regions in exporting countries; the next two terms represent transportation costs from producing regions to domestic consuming regions for domestic consumption by truck and rail. The fourth and fifth terms represent transportation cost from producing regions to river access points and ports for exports, respectively. The sixth term represents barge transportation costs from river access points to ports for exports. The last term represents ocean shipping from ports in exporting countries to ports in importing countries. Production and export subsidies (s_i) were deducted from production costs, and import tariffs (r_q) were added to ocean shipping costs and to rail shipping costs in the case of Mexico.

The objective function is optimized subject to a set of constraints. Some of these are arable land constraints in exporting countries and demand constraints for each type of grain and oilseed in consuming regions in both exporting and importing countries. This objective function is optimized subject to the following constraints:

1) $$Y_{ci} \ A_{ci} \geq \sum_j Q_{cij} + \sum_p Q^R_{cip} + \sum_w Q^t_{ciw}$$

2) $$\sum_c A_{ci} \leq TA_i$$

3) $$A_{ci} \geq MA_{ci}$$

4) $$\sum_i Q_{cij} \geq D_{cj}$$

5) $$\sum_p Q_{cpq} \geq MD_{cq}$$

6) $$\sum_c \sum_i Q_{ciw} \leq LD_w$$

7) $$\sum_c \sum_i \sum_p Q^R_{cip} + \sum_c \sum_i \sum_j Q^R_{cij} \leq MR^{US}$$

8) $$\sum_i Q^R_{cip} + \sum_w Q^B_{cwp} = \sum_q Q_{cpq}$$

9) $$\sum_{i} Q^{t}_{ciw} = \sum_{p} Q^{B}_{cpw}$$

where y=yield per hectare in each country, TA=total arable land in each producing regions, MA=minimum land used for each crop in each producing region, D=forecasted domestic demand in consuming regions, MD=forecasted import demand in importing countries, LD_w=throughput capacity for grains and oilseeds at river access point W, and MR^{US} =rail capacity for grains and oilseed shipments.

Equation 1 indicates that total grains and oilseeds produced in each producing region in exporting countries should be equal to or larger than the quantities of grains and oilseeds shipped to domestic consuming regions, river access points, and export ports. Exportable surplus is total domestic production of each type of grain and oilseed minus domestic consumption of the individual crops and moved to ports by rail directly and river access points for shipments by barge to ports. Equation 2 is the physical constraint of arable land in each producing region. The next constraint represents characteristics of production activities in each producing region in exporting countries. Producers tend to produce certain crops due to their experience in production practices, the costs in switching crops, and the fact that certain segments of land are more suited to producing one crop over others. Equation 4 represents the domestic demand constraints in consuming regions in exporting countries. The total quantity of grains and oilseeds shipped from producing regions to consuming regions should be larger than or equal to the total quantities needed. Equation 5 represents the import demand constraints in importing countries. Equations 6 and 7 represent capacity in handling and shipping in export ports, river access points, and the U.S. rail system, respectively. Equation 8 is for inventory clearing at ports in exporting countries. The last constraint represents inventory clearing at river access points. The model was calibrated to reflect the flows that occurred during the early 2000s. In addition to the restrictions above, selected restrictions were imposed on the model to calibrate it to current world trade patterns and to U.S. domestic flows. These were applied in order to capture some of the peculiarities associated with world grain shipments.

Data Sources and Transformations

Production Costs, Harvest Areas, Yields and Consumption

Production costs were from Global Insights (2004b) and the variable cost per hectare was used. Harvested area, which was used as a constraint, was obtained for each crop in 44 countries/regions and 27 regions within North America. The maximum area was specified as a function of a trend which represents longer-term changes in arable land for each grain in individual countries and regions. Changes in arable land are due to changes in economic conditions, policies, and availability of water for agricultural production and trade environments. Harvested area for each crop in each producing region is specified as: $HA_t = \gamma_0 + \gamma_1 Trend + e_t$ where *HA* is harvested area, and *Trend* is time trend from 1980 to 2004. The model is estimated with time series data of *HA* from 1980 to 2004 and the estimated model is used to forecast *HA* for the projection period. The estimated value was posed as maximum available land for crop production in each country and region.

Yield for each crop in individual countries/regions is specified as a function of a trend which represents advancement in farming technology. The yield equation for each crop and each producing region is specified as: $\ln YLD_t = \gamma_0 + \gamma_1 \ln Trend + e_t$ where *YLD* is the yield in mt/ha and *Trend* is time trend commencing from 1980. Annual data for harvested area (*HA*) and yield (*YLD*) for the years 1980- 2004 were obtained from the *PS&D Data Base* (U.S. Department of Agriculture, Foreign Agricultural Service). The estimated model was used to forecast yields of each crop for the projection period.

Consumption functions were estimated for each crop and consuming country/region. Income elasticities for the 54 countries were estimated using a two-step procedure. First, a consumption function was estimated for each country: $C=f(Y)$ for each crop where C is per capita consumption and Y is income. These results generated an income elasticity for each country and crop, E_{ci}. Second, a relationship was estimated between the elasticity and the per capita income. The notion here is that as incomes increase, there is a tendency for the income elasticity to decline. Thus, as a country's income changes, there is a shift in consumption to be similar to other countries at similar stages in development. An equation was estimated to determine the rate of change in income elasticities as per capita income increases. The model was $E_{ci} = \gamma_{ci0} + \gamma_{ci1}(Y_{ci})^{\lambda}$ where c=crop and i=country. The estimated elasticity was used to generate the consumption response to changes in per capita income. The R^2 are between 0.85 and 0.86.

Income elasticities for developed countries, United States, Japan, and Australia, are much lower than those for developing countries like Mexico, China, and Brazil. The data points move from high income and low elasticity to low income and high elasticity. Income elasticities fall from 2003 to 2025. For example, for Chinese soybeans the elasticity falls from 0.47 to 0.40. Using these estimated income elasticities, per capita consumption was calculated. The equation was specified by: $PCC_{cit} = (PCC_{cit-1}$ +(Percent change in PCI_{cit})(E_{cit}) where c=crop, 1 to 3; i=country, 1 to 16; and t=year, 2004 to 2025. From these results, we derived the total domestic demand for each grain in each country or region.

Import demand (MD) for each crop in the countries/regions was defined as $MD_{cq} = DD_{cq} - DP_{cq}$ where DP is total production and DD is domestic consumption. The model determines the level of import demand. If MD is positive, country q is an importing country, while country q is an exporting country if MD is negative.

Modal Shipping Costs and Restrictions

Shipping costs were defined for each mode and route. Ocean shipping rates were taken from Maritime Research, Inc., for the period 1994 to 2004. Truck rates were defined from Dager (2007) for shipments to the river and from data reported by the U.S. Deparment of Agriculture, Agricultural Marketing Service (AMS) (2001-2002) for domestic shipments. Rate functions were estimated and combined with distances to define truck rate estimates for each origin and destination in the United States. Rail rates were derived from the Surface Transportation Board waybill data set. Average rates were derived for each year, origin, and destination, including barge reaches. Separate rate matrixes were derived for domestic and export shipments. Shipments to reaches and export ports were not allowed for those movements in which rail rates were not observed (which would be due to rail being non-competitive on that route) and/or where observed rail shipments were nil.

A rail capacity restriction was imposed and was derived from data reported in USDA-AMS. Finally, a set of restrictions was applied to rail movements that, for varying reasons, are virtually nil. These were discovered through the calibration process by comparing model results with observed flows and then verifying reasons for differences. These are listed in detail in (Wilson et al., 2007).

Barge shipping costs were derived for origins on the Mississippi River System and encompassed all origins within that geographic region. These reaches are defined as: Reach 1, Cairo to LaGrange (St. Louis); Reach 2, LaGrange to McGregor (Davenport); Reach 3, McGregor to Minneapolis (Mpls); Reach 4, Illinois River (Peoria); Reach 5, Cairo to Louisville (Louisville); and Reach 6, Cincinnati (Cincinnati). The barge shipping cost was defined as $B=B_r + D_r$, where B_r is the barge rate defined above which is a function of volume shipped from Reach *r*, and *D* is a "delay cost" for Reach *r*. Barge rates were defined as estimated barge rate functions for each reach (Wilson et al., 2006). A delay cost was defined for each of the reaches by the U.S. Army Corps of Engineers (ACE) following the procedures defined in Oak Ridge National Laboratory (2004) and as used in (Wilson et al., 2006).