Response of North Dakota Soybean Flows to the Panama Canal Expansion: A Positive Mathematical Programming Model

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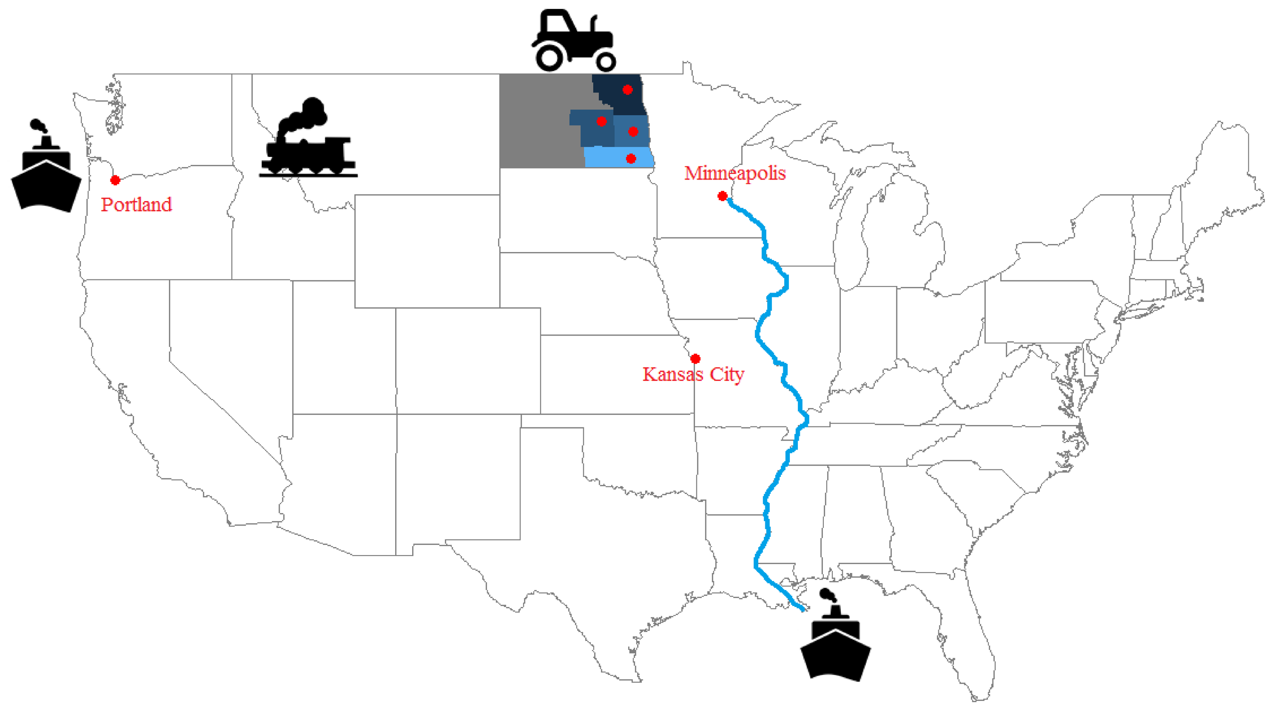
INTRODUCTION

I use a calibrated spatial and intertemporal programming model to examine how the Panama Canal Expansion (PCE) may change soybean shipments between North Dakota crop reporting districts and U.S. export and consumption locations.

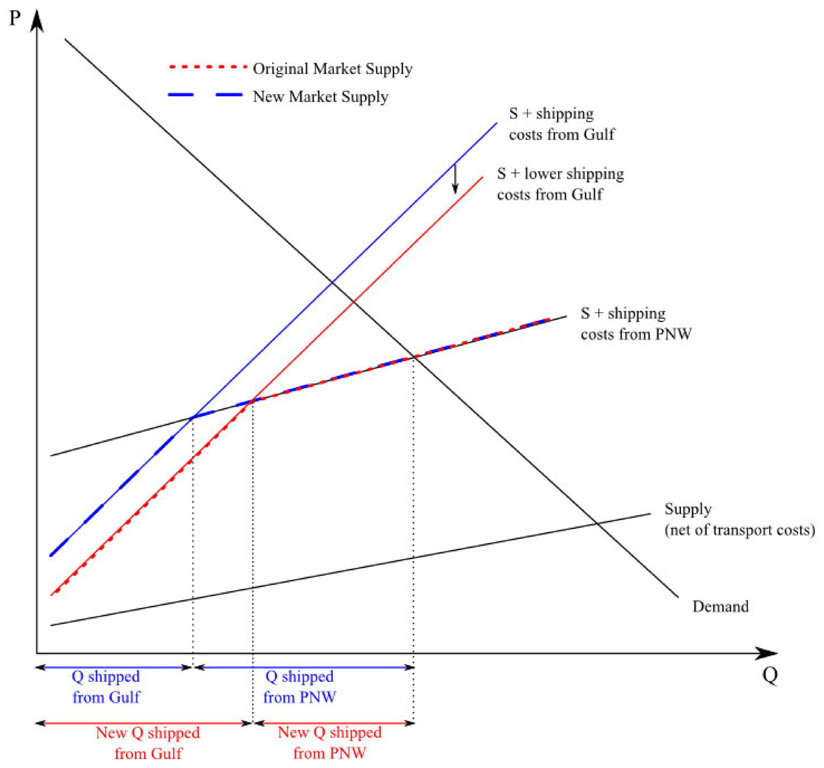


BACKGROUND

- The PCE opened in June 2016 and approximately doubled the tonnage capacity of the canal.
  - An additional and larger shipping channel was added
  - Ships with greater capacity can now traverse the canal, 120,000 DWT versus 52,500 DWT

Photo Source: Panama Canal Authority (micanaldepanama.com/expansion/photos)

- U.S. grain and oilseed exports dominate the East to West dry bulk traffic through the canal.
- Benefits of the PCE have not yet been fully realized due to long inventory and improvement cycles in the shipping industry.
- According to a 2011 Informa Economics report, soybean shipping costs from the Gulf of Mexico to Asia may decrease by 35 cents per bushel due to the PCE.
- Most literature about the PCE examines container shipping. There also exists some agricultural economics literature on how the Panama Canal Expansion may influence dairy and cotton global trade flows. I contribute research about dry bulk shipping of oilseeds.
- Programming models are the standard technique to evaluate changes in infrastructure. But most models of U.S. grain and oilseed shipments are uncalibrated. Here I take advantage of positive mathematical programming techniques to calibrate over both time and space.



From the perspective of a firm marketing U.S. soybeans to China, the main export locations are the Pacific Northwest or the Gulf of Mexico. Soybeans bids are typically lower at Gulf ports, however ocean shipping costs are also higher from the Gulf. The PCE lowers the cost of sourcing soybeans from Gulf. North Dakota is a key area to study because it is on the economic divide of shipping grain and oilseed either west or south.

METHOD

Steps:

1) Specify an intertemporal partial equilibrium model of soybean flows from North Dakota.
2) Calibrate to historical data using positive mathematical programming techniques.
3) Determine joint distributions of soybean prices and transportation costs to simulate monthly observations for 5000 marketing years.
4) Solve the calibrated programming model with simulated data and account for the PCE by increasing prices of locations likely to benefit.

STEP 1

Sets		
i	$CRD3,\ CRD5,\ CRD6,\ CRD9$	North Dakota origin regions
j	$mn-wi,\ midland,\ pnw$	Rail destination regions
k	$CRD3,\ CRD5,\ CRD6,\ CRD9$	Truck destination locations
t	$1,2,3,\ldots,72$	Months from Sept 2010 to Aug 2016
Variables		
x_{ijt}	Rail quantity shipped from i to j during month t	
y_{ikt}	Truck quantity shipped from i to k during month t	
s_{it}	Storage in i during month t	
Parameters		
p_{jt}	Price in location i during month t	
c_{ijt}	Shipping cost between i and j during month t	
g	Storage cost	
b_{it}	Production in i during month t	

Shipping origins and destinations are shown in the graphic on the top left. For soybean origin locations I selected the elevator closest to the center of gravity of all elevators within each ND crop reporting district (CRD). For destinations, I selected the most likely location within each region: the Pacific Northwest (WA, OR, and ID), Minnesota-Wisconsin, and Midland (all other states outside of ND). Parameters for these locations were generated using the sources below.

- North Dakota soybean prices: GeoGrain
- Prices in Minneapolis, Portland , and Kansas City: USDA AMS
- Rail costs: BNSF rail mileage calculator and USDA AMS Grain Transportation Report
- Truck costs: Google maps and USDA Agricultural Marketing Service Grain Transportation Report
- Storage costs: assumed to be $0.05/bu/month
- Production and storage capacity in North Dakota: Upper Great Plains Transportation Institute

The programming model maximizes the industry surplus of shipping soybeans subject to supply and non-negativity constraints. Monthly choice variables are storage in each crop reporting district, truck shipments between crop reporting districts, and the variable of interest which is rail flows to main U.S. soybean demand regions.

$$\max_{x\,y\,s} \underbrace{\sum_i\sum_j\sum_t [p_{jt}-p_{it}-c_{ijt}]x_{ijt}}_{\text{rail shipment surplus}} + \underbrace{\sum_i\sum_j\sum_t [p_{it}-p_{kt}-c_{ikt}]y_{ikt}}_{\text{truck shipment surplus}} - \underbrace{\sum_i\sum_t g s_{it}}_{storage\ cost}$$

subject to

$$\underbrace{s_{it}-s_{i\,t-1}}_{change\ in\ storage} = b_{it} + \sum_i y_{ikt} - \sum_k y_{ikt} - \sum_j x_{ijt}$$

$$x_{ijt},\ y_{ikt},\ s_{it} \geq 0$$

Calibration Constraints	Dual variables
$CY1min_{ij} \leq \sum_{t1} x_{ijt} \leq CY1max_{ij}$	Lower bound γ_{ij}^1 Upper bound λ_{ij}^1
$CY2min_{ij} \leq \sum_{t2} x_{ijt} \leq CY2max_{ij}$	Lower bound γ_{ij}^2 Upper bound λ_{ij}^2
$CY3min_{ij} \leq \sum_{t3} x_{ijt} \leq CY3max_{ij}$	Lower bound γ_{ij}^3 Upper bound λ_{ij}^3
$CY4min_{ij} \leq \sum_{t4} x_{ijt} \leq CY4max_{ij}$	Lower bound γ_{ij}^4 Upper bound λ_{ij}^4
$CY5min_{ij} \leq \sum_{t5} x_{ijt} \leq CY5max_{ij}$	Lower bound γ_{ij}^5 Upper bound λ_{ij}^5
$totshipmin_t \leq \sum_i\sum_j x_{ij} \leq totshipmax_t$	Lower bound ρ_t Upper bound μ_t

Additional constraints on rail flows are based on data from Upper Great Plains Transportation Institute reports. One constraint imposes a range on the total amount of soybeans shipped from North Dakota each month. Another set of constraints imposes a range on the amount shipped between each origin and destination pair during July-June "crop years," denoted by t1 to t5. These constraints provide the model with additional information about seasonality and the transportation system.

STEP 2

I solve the model in step 1 using GAMS. With the dual values from the step 1 solution, the linear objective function can be written as a non-linear function that essentially imposes a cost for deviating from the observed soybean flows.

$$\begin{aligned}\max_{x\,y\,s} &\sum_i\sum_j\sum_t [p_{jt}-p_{it}-c_{ijt}]x_{ijt} + \sum_i\sum_k\sum_t [p_{it}-p_{kt}-c_{ikt}]y_{ikt} - \sum_i\sum_t g s_{it}\\
&\boxed{\begin{aligned}&-\sum_i\sum_j\left[\left(\sum_{t1} x_{ijt}\right)\frac{\lambda_{ij}}{2MYmax_{ij}}\left(\sum_{t1} x_{ijt}\right)\right]\\ &+\sum_i\sum_j\left[-2\gamma_{ij}^1+\left(\sum_{t1} x_{ijt}\right)\frac{\gamma_{ij}}{2MYmin_{ij}}\left(\sum_{t1} x_{ijt}\right)\right]\end{aligned}} \quad \text{Origin-destination flow calibration}\\
\text{Seasonal flow calibration} \quad &\boxed{\begin{aligned}&-\sum_t\left[\left(\sum_i\sum_j x_{ijt}\right)\frac{\rho_t}{totshippedmax_t}\left(\sum_i\sum_j x_{ijt}\right)\right]\\ &+\sum_t\left[-2\mu_t+\left(\sum_i\sum_j x_{ijt}\right)\frac{\mu_t}{totshippedmin_t}\left(\sum_i\sum_j x_{ijt}\right)\right]\end{aligned}}\end{aligned}$$

subject to

$$s_{it}-s_{i\,t-1} = b_{it} + \sum_i y_{ikt} - \sum_k y_{ikt} - \sum_j x_{ijt}$$

$$x_{ijt},\ y_{ikt},\ s_{it} \geq 0$$

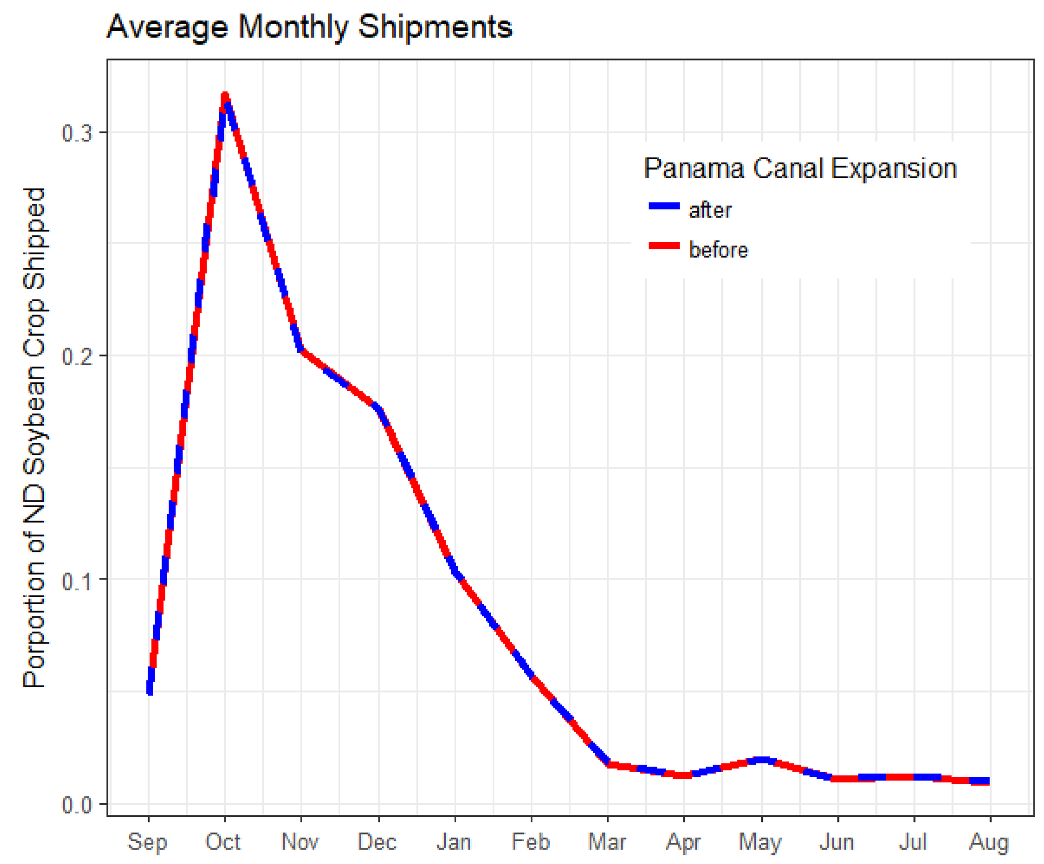
I use average dual values for crop year origin-destination pairs and total shipments each month to create a calibrated positive mathematical programming model for a single September to August marketing year.

STEP 3

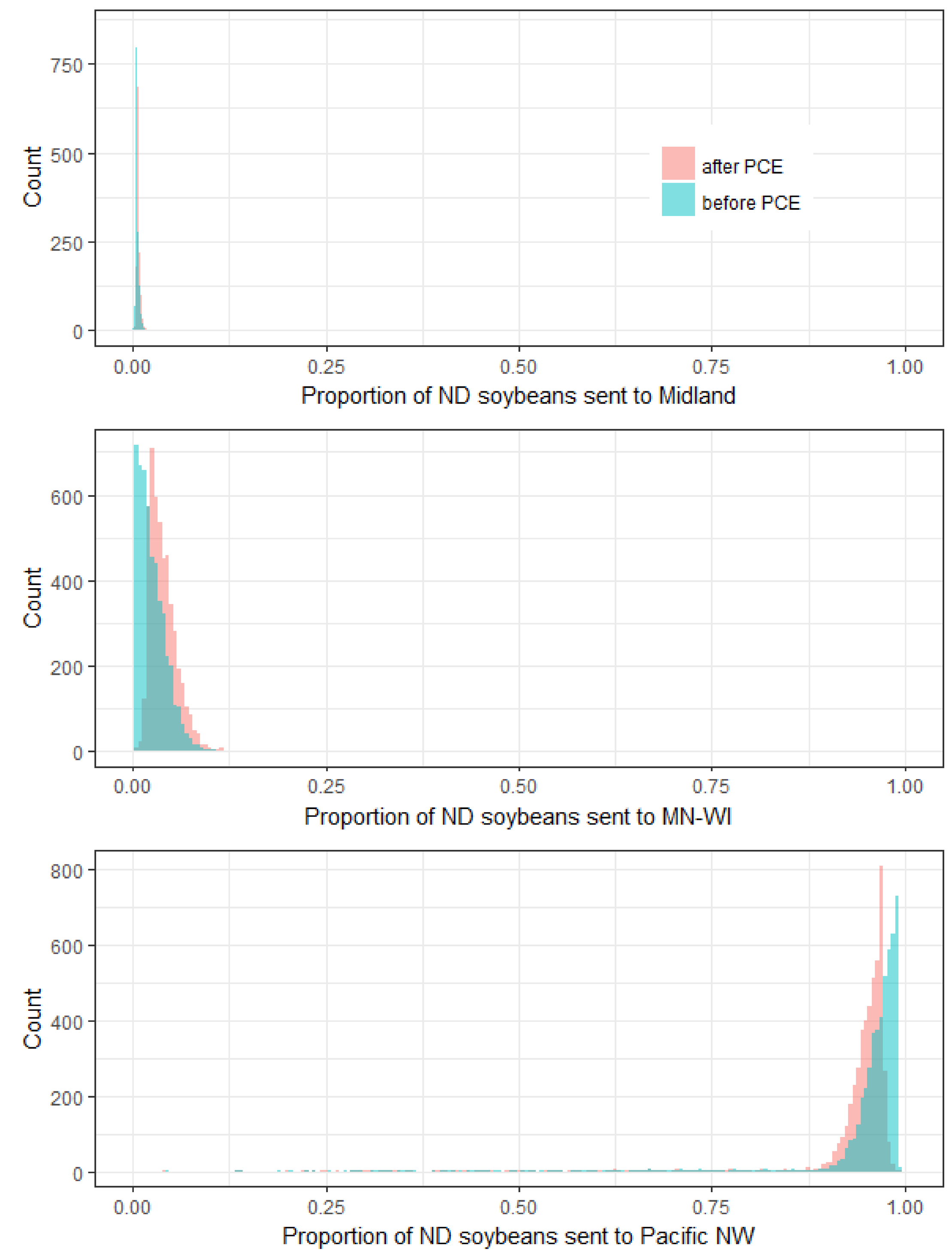
Using maximum likelihood test statistics, I determine marginal and pairwise joint distributions of soybean bid and transportation cost parameters. Monthly observations of these parameters are simulated using a vine copula to allow for asymmetric dependence. Prices of subsequent months were selected based on first differences of Portland soybean bids. In total I simulated 5000 soybean marketing years.

STEP 4

I use the simulated data from step 3 to solve the positive mathematical programming model and obtain base values before the PCE. Then, I account for a reduction in shipping costs through the Gulf of Mexico with price increases in Minnesota-Wisconsin and Midland. The increase is two percent of prices, about 15 to 25 cents per bushel.



In the figure above, the seasonal shipping pattern is the same after accounting for the Panama Canal Expansion. This indicates the calibration procedure accounting for time is effective. The histograms below show that some soybeans always go to Minnesota-Wisconsin or Midland, providing evidence that the spatial dimension is also well calibrated.



After the PCE, 1.5 percent fewer North Dakota soybeans are exported through Portland. This amounts to more than two million bushels. Most of these soybeans go to Minnesota-Wisconsin instead, and are sourced from North Dakota regions close to Minneapolis. We can expect approximately five to six more 110 car unit train shipments to Minneapolis.

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