# International trade in agricultural products at the U.S. state level[a]

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*Abstract: We develop a structural model that leverages both input-output accounts and economic-geography to estimate state-level imports and exports of agricultural products. We develop a method that allocates farm revenue across observed exports and allocates imports across state-level absorption. The model accounts for economic geography under a gravity theory. The more proximate farm output is to observed export nodes, for example, the greater is the export share. Our method generates more realistic estimates of the link between farms, agricultural products, domestic absorption of these goods, and international trade. This exercise is a key component in assessing a given state's exposure to trade shocks. To illustrate this we provide descriptive reports that indicate differences in our estimates relative to other methods.*

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## 1. Introduction

An individual U.S. state's exposure to international markets is often a topic of social commentary and economic analysis. Informed analysis seems to require an estimate of a state's exports and imports. Unfortunately, published measures of state-level trade often fall short of accurately reflecting trade exposure. U.S. Customs tracks international trade at specific ports of entry (exit) rather than the ultimate destination of imports or source of export shipments. In the official state-trade statistics from the U.S. Census Bureau too much trade exposure is reported

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for states with major sea ports or border crossings, and nearly zero exposure for interior states producing major export commodities like wheat and soybeans. An alternative is to simply share total U.S. exports to states based on production shares. While transparent, this method fails to account for trade costs over economic geography and the co-location embeded in input-output relationships.

In this paper we develop and apply a new method for estimating state-level international trade in agricultural products that incorporates geographic trade frictions. The method is based on a fundamental proposition from trade theory, which posits equal absorption shares of regionally differentiated goods in the absence of trade frictions. Adopting this as an assumption allows us to calibrate a commodity-specific Armington demand system to input-output accounts that establish supply and demand vectors for each state and each port. We then utilize the structure with trade frictions included to establish the benchmark flows of goods from the point of production to domestic uses and port-level exports. Similarly, we distribute port-level imports to their use in specific states. While our primary focus is on international trade the method yields a bilateral interstate trade matrix for each commodity.

Our work complements recent advances in open-source calculations of state input-output accounts by the Wisconsin National Data Consortium (WiNDC).[1] The WiNDC project focuses on publicly available data sources and a series of routines that generate micro-consistent subnational accounts. Previously available subnational accounts where both expensive and proprietary, which made them less ideal for research.[2] The academic based WiNDC project has many advantages including its accessibility, transparency, and extensibility to particular research questions.

Representing bilateral interstate and state-level international trade in the WiNDC accounts remains as a challenge. A lack of reliable data on interstate trade favors a *pooled* national market formulation, which ultimately limits the structural options for researchers. At first the U.S. Department of Commerce's Bureau of Census (Census) reports in the Commodity Flow Survey (CFS) might be considered the best source for bilateral state trade, but these data suffer from a fundamental problem. The CFS tracks shipments of goods not the goods themselves. For example, a rail shipment of a bushel of corn from Eastern Nebraska to Kansas City plus the barge shipment of the same bushel from Kansas City to New Orleans escalates the quantity (and value) of the actual corn shipped. This problem, of double counting in the CFS data, is noted by Anderson and van Wincoop (2003) who correct the CFS interstate trade flows assuming they are exaggerated by a factor of 2.08. Our proposed method for generating bilateral interstate trade imposes

[1] See https://windc.wisc.edu/.
[2] The IMPLAN (https://implan.com/) state accounts are an example of a closed-source commercial alternative.

consistency between state-level production and aggregate absorption and export demand.

The state-level *international* trade in the core WiNDC accounts is also a known weakness. The WiNDC trade data is from Census reports of imports and exports by state, but these are actually measured by Port of Entry.[3] The port from which agricultural exports exit the United States, however, are not necessarily or even likely located in the States where those products are produced. For instance, corn exports departing the ports located in the New Orleans Port District were not necessarily grown in the State of Louisiana. In fact, the large volume of Louisiana exports of grains (as reported by Census and thus inferred in the WiNDC accounts) is only explained by Louisiana's purchase of grains through the pooled national market. On the supply side, the excess supply of corn in a state like Nebraska does not leave its Port of Entry in Omaha, but rather is absorbed by the pooled national market. Looking at the Census data Louisiana exports a significant quantity of corn but Nebraska, a key corn producer, does not. A better representation would attribute international exports (and imports) of agricultural products to the state of production (and absorption).

Faced with the problematic Census state-trade data, the U.S. Department of Agriculture's Economic Research Service (ERS) generates an alternative measure of state agricultural exports based on cash receipts. For these estimates, the products that make up U.S. agricultural exports are grouped to match the 24 product groups in U.S. farm sales estimates. For each of these 24 product groups, U.S. agricultural exports are allocated by State in approximate proportion to the State's share of national cash receipts for that product group. Thus, Nebraska, with 12.4 percent ($8.9 billion) of U.S. cash receipts for corn in 2021, is estimated to have accounted for 12.6 percent ($2.3 billion) of U.S. corn exports that year (U.S. Department of Agriculture, 2023a,b). In contrast, the Census Bureau's State Trade Data indicate Nebraska's corn exports (HS-6 100590) totaled about $609 million in 2021 (U.S. Department of Commerce, 2023).

Neither of these two estimates are based on a comprehensive assessment of the use of Nebraska's corn production, along the lines of USDA's PSD (Production, Supply, and Distribution) Online Database (U.S. Department of Agriculture, Foreign Agricultural Service, 2023). Some rough estimates are commonly circulated in the industry, however. For instance, Groskopf and Silva (2018) estimate that about 40 percent of Nebraska's 2018 corn crop was used as feedstock for ethanol production within the State. The Nebraska Corn Board (2023a) indicates that "about 16 percent of Nebraska's corn crop is fed to livestock within Nebraska" and that "about 40 percent of the corn grown in Nebraska is fed to livestock somewhere in the United States or around the world." With respect to exports,

[3] The Census Bureau disseminates export and import statistics by Port of Entry at the HS-6 level (U.S. Department of Commerce, 2023).

the Nebraska Corn Board (2023b) estimates that international exports account for about 6 percent of the use of Nebraska's corn production.

Our purpose is to inform the key question of how much of a states production of specific agricultural goods are exported and how much is disbursed to each of the fifty states (plus D.C.). We use a structural gravity model following the theory of Anderson and van Wincoop (2003). A presentation of the full theory and its development is given by Yotov et al. (2016). There are two specific features of this theory that we leverage in developing our estimates of interstate agricultural trade and the flows of agricultural products between ports and states. First is the assumption of identical and homothetic preferences. This provides an anchor point for calibration, where in the absence of trade frictions expenditure shares on regionally differentiated goods are the same across regions. The second assumption is that trade cost are of the iceberg type. That is, they are paid in units of the good being shipped. This allows us to establish trade at normalized prices at both the frictionless anchor and the benchmark equilibrium.

The remainder of the paper is organized as follows: In the next section we consider the frictionless anchor point suggested in the gravity theory. In Section 3 we present our model and method in the context of the structural model. In Section 4 we itemize the data sources. Results are presented in Section 5 with a comparison to other methods and including sensitivity analysis. Concluding remarks are offered in section 6.

## 2. Gravity Theory and the Frictionless Anchor

We start by considering a structural gravity model under regionally differentiated goods as presented by Anderson and van Wincoop (2003) and Yotov et al. (2016). We generally adopt the notation of Yotov et al. (2016) with the exception that we index goods using $i \in I$ and regions (states) using $s \in S$ or $r \in S$. We proceed in this section by suppressing the index on the good, which is consistent with the one-sector general-equilibrium treatment of Anderson and van Wincoop (2003). The structure remains intact for each individual good under *separability* as demonstrated by Larch and Yotov (2016, Appendix B).[4] Another simplification in the Anderson and van Wincoop (2003) theory as presented is the suppression of intermediate inputs to production. The extension to accommodate measured intermediates requires us to consider regional supply of a good to be measured as gross output (not value added) and expenditures on the good to include intermediates as well as final demand—absorption.

A fundamental assumption of the Anderson and van Wincoop (2003) structure

[4] Separability such that each good abides by the fundamental one-sector Anderson and van Wincoop (2003) gravity system requires additional assumptions. The assumptions made by Larch and Yotov (2016, Appendix B) are shown to be sufficient.

is an identical and linearly homogeneous *Armington* aggregation of the regionally differentiated goods.[5] This aggregate is then available for absorption in terms of intermediate inputs in production and final demand. Let us denote supply of this *Armington* aggregate (or composite) in region $s$ as $A_s$. Assuming a Constant Elasticity of Substitution (CES) aggregator we have an analog to equation (1-1) of Yotov et al. (2016, p13):

$$A_s = \left[ \sum_r \alpha_r^{\frac{1-\sigma}{\sigma}} c_{rs}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}. \tag{1}$$

This technology is better represented in its dual form as the *minimized* unit-cost function, which embeds optimal sourcing of each regional variety. Let $p_r$ indicate the factory-gate price, and let $t_{rs}$ be the trade cost index associated with shipping from $r$ to $s$. With no trade costs the $t_{rs}$ would be one. We also assume symmetry in trade costs, $t_{rs} = t_{sr}$. An agent in region $s$ will minimize expenditures ($\sum_r p_r t_{rs} c_{rs}$) conditional on $A_s$. Under linear homogeneity, expenditures (cost) is linear in $A_s$, so we can choose any scale of $A_s$ to represent the technology. Conditional on a scale of one unit ($A_s = 1$), the unit-cost or, equivalently, the unit-expenditure function is

$$P_s = \left[ \sum_r (\alpha_r p_r t_{rs})^{1-\sigma} \right]^{\frac{1}{1-\sigma}}. \tag{2}$$

$P_s$ can be interpreted as an ideal price index or equivalently the marginal cost of a unit of the composite $A_s$. The corresponding level of expenditures is

$$E_s = P_s A_s. \tag{3}$$

The remainder of the equilibrium is somewhat mechanical. The nominal value of supply, denoted $Y_r$, is given by the product price and the fixed supply quantity

$$Y_r = p_r q_r. \tag{4}$$

Demand is derived by applying the envelope theorem to minimized expenditures and then summing across the potential destinations. Market clearance is thus given by

$$q_r = \sum_s A_s \frac{\partial P_s(\boldsymbol{p})}{\partial p_r}. \tag{5}$$

It is important to note the operation of so called *iceberg* transport costs in terms of the market clearance condition. From the perspective of the exporter in $r$ the quantity shipped equals $t_{rs} c_{rs}$ at a price of $p_r$. From the perspective of the importer

[5] The seminal analysis that viewed international trade data as being comprised of regionally differentiated goods comes from Armington (1969).

in region $s$ the quantity that arrives for consumption is $c_{rs}$ at a price of $t_{rs}p_r$.[6]

In the context of the one sector Anderson and van Wincoop (2003) environment equations (2)–(5) represent a Walrasian general equilibrium (see Balistreri and Hillberry, 2008). In the general equilibrium the quantity supplied $q_r$ is a fixed endowment quantity, and expenditures are income ($E_r \equiv Y_r$). With $n$ regions there are $4n$ equilibrium conditions and $4n$ variables interpreted as follows: $Y_r$ is nominal income; $A_r$ is an index on welfare; $P_r$ the true-cost-of-living index, and $p_r$ is the endowment price at its origin. We have a Walrasian equilibrium so a unique solution requires a price normalization.

The focus in the structural gravity literature is on nominal bilateral trade. To be concrete, under our CES assumption, we can pull out a bilateral trade term from the right-hand side of the market clearance condition (5). In nominal terms this is

$$x_{rs} = p_r A_s \frac{\partial P_s(\boldsymbol{p})}{\partial p_r}. \tag{6}$$

Taking the derivative and converting this to uncompensated demand (using $Y_s = E_s = P_s A_s$ from equation 3) we have

$$x_{rs} = Y_s \left( \frac{\alpha_r p_r t_{rs}}{P_s} \right)^{1-\sigma}. \tag{7}$$

Using equations (4) and (5) nominal market clearance can be represented as

$$Y_r = \sum_s Y_s \left( \frac{\alpha_r p_r t_{rs}}{P_s} \right)^{1-\sigma}. \tag{8}$$

Dividing through by total nominal supply $Y^w \equiv \sum_r Y_r$ and factoring out the price-weighted source region preference we have

$$\frac{Y_r}{Y^w} = (\alpha_r p_r)^{1-\sigma} \sum_s \frac{Y_s}{Y^w} \left( \frac{t_{rs}}{P_s} \right)^{1-\sigma}, \tag{9}$$

To simplify the exposition define the following source-region index as in Anderson and van Wincoop (2003):

$$\Pi_r \equiv \left[ \sum_s \frac{Y_s}{Y^w} \left( \frac{t_{rs}}{P_s} \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}, \tag{10}$$

[6] Conditional demand at the destination is

$$c_{rs} = A_s \frac{\partial P_s(\boldsymbol{p})}{\partial (p_r t_{rs})},$$

but at the source it is

$$t_{rs} c_{rs} = t_{rs} A_s \frac{\partial P_s(\boldsymbol{p})}{\partial (p_r t_{rs})} = A_s \frac{\partial P_s(\boldsymbol{p})}{\partial p_r}.$$

so equation (9) is given as

$$\frac{Y_r}{Y^w} = (\alpha_r p_r)^{1-\sigma} \Pi^{1-\sigma}. \tag{11}$$

Using this equation to substitute the price-weighted preference parameters out of equation (7) give us the fundamental structural gravity equation (Anderson and van Wincoop, 2003):

$$x_{rs} = \frac{Y_r Y_s}{Y^w} \left( \frac{t_{rs}}{\Pi_r P_s} \right)^{1-\sigma}. \tag{12}$$

The structural gravity system used to analyze bilateral trade would include the gravity equation (7), as well as the indexes specified in equations (2) and (10). Anderson and van Wincoop (2003) discuss these indexes in terms of inward multilateral resistance ($P_r$) and outward multilateral resistance ($\Pi_r$). The product of the inward and outward indexes reflect the fact that, in addition to the specific bilateral trade cost on the link in question, the trade flow on that link is impacted by the exporter's relative access to all markets and the importer's relative access to all markets.

For our purpose in this paper a key lesson from the structural gravity system is the fact that in the absence of trade frictions each region will consume its global expenditure share of goods from any source region. If we impose $t_{rs} = 1 \;\; \forall rs$ so all regions face the same price vector and therefore the same price index $P_s = P^w \;\; \forall s$. Furthermore, with no trade frictions, equation (10) indicates that the $\Pi_r$ are also invarient across regions ($\Pi_r = \Pi^w \;\; \forall r$). Nominal trade in the absence of frictions is thus

$$x_{rs} = \frac{Y_r Y_s}{Y^w} \Gamma, \tag{13}$$

where $\Gamma \equiv (\Pi^w P^w)^{\sigma-1}$. The only way that equation (13) satisfies market clearance is if $\Gamma = 1$ when there are no trade frictions:

$$\sum_s x_{rs} = Y_r \frac{\sum_s Y_s}{Y^w} = Y_r.$$

To conclude our discussion of the frictionless anchor for calibration define $\theta_s = Y_s / Y^w$ such that nominal trade flows under no trade frictions equals the nominal supply weighted by the expenditure share

$$x_{rs} = \theta_s Y_r; \tag{14}$$

or equivalently expenditures at the destination weighted by the supply share

$$x_{rs} = \theta_r Y_s. \tag{15}$$

Calibration of a model consistent with the theory to the frictionless equilibrium only requires measures of nominal supply in $r$ and nominal absorption in $r$. With the model calibrated to the implied bilateral trade at the frictionless anchor we can use a well specified gravity system, like equations (2)–(5), to estimated bilateral trade flows conditional on any set of bilateral trade costs. Of course, in a model with states trading with other states and ports (which facilitate trade with the rest of the world) the structure must be extended beyond the simple Anderson and van Wincoop (2003) model.

### 3. Structural Model

In this section we develop a structural gravity model in the spirit of the canonical theory presented above. We use this structure to attributes a state's measured production of an agricultural product, like wheat (WHT), to port-level exports or absorption by one of the 51 US regions (50 states plus DC). Similarly, the model simultaneously allocates port-level imports to each of the 51 US regions. To set up the model let us index commodities by $i \in I$. As a first pass we focus on the 11 aggregate agricultural goods in the 43 sector GTAP-WiNDC accounts:

| | |
|---|---|
| C_B | Sugar cane, sugar beet |
| CTL | Bovine cattle, sheep, goats and horses |
| GRO | Cereal grains nec |
| OAP | Animal products nec |
| OCR | Crops nec |
| OSD | Oil seeds |
| PDR | Paddy rice |
| PFB | Plant-based fibers |
| V_F | Vegetables, fruit, nuts |
| WHT | Wheat, and |
| WOL | Wool, silk-worm cocoons. |

US states are indexed by $s \in S$ or $r \in S = \{AL, AK, AZ, \ldots, WY\}$. In addition, we observe imports and exports at a Port of Entry. We index the 40 ports by $k \in K$ as listed:

| | | | |
|---|---|---|---|
| AK_ANCH | Anchorage | AL_MOBI | Mobile |
| MD_BALT | Baltimore | LA_NEWO | New Orleans |
| MA_BOST | Boston | NY_NEWY | New York City |
| NY_BUFF | Buffalo | AZ_NOGA | Nogales |
| SC_CHAR | Charleston | VA_NORF | Norfolk |
| IL_CHIC | Chicago | NY_OGDE | Ogdensburg |
| OH_CLEV | Cleveland | ND_PEMB | Pembina |
| OR_COLU | Columbia-Snake | PA_PHIL | Philadelphia |
| TX_DALL | Dallas-Fort Worth | TX_PRTA | Port Arthur |
| MI_DETR | Detroit | ME_PORT | Portland |
| MN_DULU | Duluth | RI_PROV | Providence |
| TX_ELPA | El Paso | CA_SAND | San Diego |
| MT_GREA | Great Falls | CA_SANF | San Francisco |
| HI_HONO | Honolulu | GA_SAVA | Savannah |
| TX_HOUS | Houston-Galveston | WA_SEAT | Seattle |
| TX_LARE | Laredo | VT_STAL | St. Albans |
| CA_LOSA | Los Angeles | MO_STLO | St. Louis |
| FL_MIAM | Miami | FL_TAMP | Tampa |
| WI_MILW | Milwaukee | DC_WASH | Washington |
| MN_MINN | Minneapolis | NC_WILM | Wilmington. |

As a rule we will assume that there is a well defined mapping from the farm cash-receipts commodity $i$ and an aggregation of the (six-digit) trade and demand data in the GTAP classification, so that $i$ refers to both.

The goal of our exercise is to estimate the following flows of goods between states and ports:

| | |
|---|---|
| $\hat{X}_{irs}$ | The bilateral flow of commodity $i$ from state $r$ absorbed in state $s$, |
| $\hat{E}_{irk}$ | Exports of commodity $i$ from state $r$ through port $k$; and |
| $\hat{M}_{ikr}$ | Imports of commodity $i$ at port $k$ absorbed in state $r$. |

The challenge is that we have limited data. In the GTAP-WiNDC state-level input-output accounts we observe the value of absorption of good $i$ in each state, denoted here as the product of the price index and composite good: $P_{is}A_{is}$. Total absorption is consistent with the state-level use of good $i$ in intermediates and final demand. We also observe cash receipts from supply in state $r$ as $p^y_{ir}Y_{ir}$, where $Y_{ir}$ is the output quantity and $p^y_{ir}$ is the factory gate price. We also observe the value of imports and exports of good $i$ at port $k$ as $M_{ik}$ and $E_{ik}$. These observations of the totals discipline the estimated flows through the following accounting identities:

$$P_{is}A_{is} \equiv \sum_r \hat{X}_{irs} + \sum_k \hat{M}_{iks}. \qquad (16)$$

In words, the value of observed absorption of good $i$ for intermediate use or final demand in region $s$ ($P_{is}A_{is}$) is the same as the value of demand of $i$ from all states

$r$ (including $r = s$) and all imports allocated to $s$ from ports $k$. Next we have an identity that indicates market clearance for output from region $r$. The value of output of $i$ from $r$ ($p^w_{ir}Y_{ir}$) is exhausted on shipments to other states and ports of export.

$$p^w_{ir}Y_{ir} \equiv \sum_s \hat{X}_{irs} + \sum_k \hat{E}_{irk}. \tag{17}$$

For international trade we equates the value of total imports of good $i$ at port $k$ with its estimated disbursement to states $r$

$$M_{ik} \equiv \sum_r \hat{M}_{ikr}; \tag{18}$$

and the total value of exports at port $k$ must equal the value of shipments to that port from across the states $r$

$$E_{ik} \equiv \sum_r \hat{E}_{irk}. \tag{19}$$

These linear relationship establish consistency of the solution estimates, but we need a structural model to translate the observed data, on the right-hand side of (16)–(19), into the estimated component flows.

Like the relatively simple model in Section 2, we build the structural model around the unit-cost function for *Armington* aggregation. As an empirical tool, however, we specify a more complex nested CES structure. For a state $s$ absorbing Armington good $A_{is}$ the relevant components include goods $i$ produced in that state, goods $i$ produced in other states $r \neq s \in S$, and goods $i$ imported from ports $k \in K$. Let us denote the relevant prices $p^y_{ir}$ as the factory-gate price of good $i$ in any state $r$, and $p^m_{ik}$ as the price of import $i$ landed (import-duty paid) at port $k$. The unit-cost of $A_{is}$ is given by

$$\begin{aligned} P_{is} = \Bigg[ & \left( \theta_s (t_{ss} p^y_{is})^{1-\sigma_{ln}} + \left[ \sum_{r \neq s} \theta_r (t_{rs} p^y_{ir})^{1-\sigma_{nn}} \right]^{\frac{1-\sigma_{ln}}{1-\sigma_{nn}}} \right)^{\frac{1-\sigma_{dm}}{1-\sigma_{ln}}} \\ & + \left( \sum_k \theta_{ik} (t_{ks} p^m_{ik})^{1-\sigma_{mm}} )^{\frac{1-\sigma_{dm}}{1-\sigma_{mm}}} \right)^{\left(\frac{1-\sigma_{dm}}{1-\sigma_{mm}}\right)} \Bigg]^{\frac{1}{(1-\sigma_{dm})}} . \end{aligned} \tag{20}$$

In the first line of (20) we have a CES aggregation of the local state good with the national aggregate of other U.S. state goods at an elasticity of substitution $\sigma_{ln}$. The national aggregate of other U.S. state goods has a CES across goods of $\sigma_{nn}$. In the second line we have the CES aggregation of imports from different ports, where the elasticity of substitution is $\sigma_{mm}$. This nesting structure gives us considerable flexiblity in terms of different substitution opportunities among the various components, and facilitates our ability to perform sensitivity analysis. Note, however, that if $\sigma = \sigma_{ln} = \sigma_{nn} = \sigma_{mm}$ the nesting collapses and we revert to the simple price index suggested in equation (2) elaborated with ports as additional sources and destinations.

In (20) we replaced the parameters $\alpha_r$ in the earlier theory with standard good-specific CES weights $\theta_{ir}$ and $\theta_{ik}$. While there is a simple conversion back to the implied $\alpha$, the $\theta$ are more convinient in the context of calibrating to the frictionless flows. To illustrate, let us choose supply-quantity units at the frictionless equilibrium such that all source prices are one ($p_{ir} = p_{kr} = 1$). Then if we normalize such that $\sum_r \theta_{ir} + \sum_k \theta_{ik} = 1$ we can see that the value of the price index must also be one without trade friction ($P_s = 1 \;\; \forall s$). Furthermore it is relatively easy to see that, dispite our elaborate nesting, bilateral nominal demand is given by

$$x_{irs} = \theta_{ir} P_{is} A_{is} \;\text{ and} \tag{21}$$

$$x_{iks} = \theta_{kr} P_{is} A_{is}; \tag{22}$$

where

$$\theta_{ir} \equiv \frac{Y_{ir}}{\sum_s Y_{is}} \left[ \frac{\sum_s Y_{is} - \sum_{k'} E_{ik}}{\sum_s Y_{is} + \sum_k M_{ik} - \sum_{k'} E_{ik}} \right], \text{and}$$

$$\theta_{ik} \equiv \frac{M_{ik}}{\sum_k M_{ik}} \left[ \frac{\sum_k M_{ik}}{\sum_s Y_{is} + \sum_k M_{ik} - \sum_{k'} E_{ik}} \right].$$

While the frist term in each of these fractions is simply the share of production by state and imports by ports they need to be corrected by the other terms. The second term in the first definition is the share of total US non-exported output to total US absorption. The second term in the second definition is the share of total imports in US absorption. With these weights was have as indicated before $\sum_r \theta_{ir} + \sum_k \theta_{ik} = 1$. The key is that these are now indicated by the observable data indicating uniform consumption of the regionally differentiated goods in the absence of friction.

We still need to develop the state-level export demand system which ships to ports that portion of output that is not absorbed in the US. Let us again use the notion of Armington aggregation to specify the port-specific unit cost, $P^x_{ik}$ of exporting some good $i$ from port $k$:

$$P^x_{ik} = \left( \sum_r \theta^x_{ir} (t_{rk} p^y_{ir})^{1-\sigma_x} \right)^{\frac{1}{1-\sigma_x}}, \tag{23}$$

where the $\theta^x_{ir} = \frac{Y_{ir}}{\sum_s Y_{is}}$ are simply the production shares. Again with no frictions and all price at one the nominal export demand at a port is just the state production share times the level of port exports:

$$e_{irk} = \theta^x_{ir} E_{ik} \tag{24}$$

Away from the frictionless equilibrium we have to hold the $\theta$ parameters fixed and calculate estimated bilateral inter-state trade, state imports, and state export. These can be calculated at an equilibrium based on the nominal demand functions implied by the unit expenditure function (20):

$$\hat{X}_{irs} = p^y_{ir} P_{is} A_{is} \frac{\partial P_{is}(\boldsymbol{p})}{p^y_{ir}}, \text{ and}, \tag{25}$$

$$\hat{M}_{iks} = p^m_{ik} P_{is} A_{is} \frac{\partial P_{is}(\boldsymbol{p})}{p^m_{ik}}, \text{ and}, \tag{26}$$

Conditional on trade costs these two equations provide the disposition of imports and bilateral trade. On the export demand side we make a similar calculation based on the unit cost of exporting at a given port. State level exports using the demand functions derived from (23) are

$$\hat{E}_{isk} = p^y_{is} E_{ik} \frac{\partial P^x_{ik}(\boldsymbol{p})}{\partial p^y_{is}}. \tag{27}$$

We can close the system by using these demand function and the data identities to specify the market clearance conditions. We maintain the observed total values as given by the right-hand sides of equations (16)–(19) in both the equilibrium with frictions and in the frictionless anchor. In this regard we are adopting the *conditional general equilibrium* environment suggested by Yotov et al. (2016, p75).

## 4. Data

1) USDA Cash receipts.
2) Census port-level trade.
3) Physical distance: State to state and state to port.
4) GTAP-WiNDC Accounts.
5) Trade costs.
6) Elasticities.

## 5. Results

**Table 1.** State exports of Soybeans (OSD)

| State | | Production ($M) | Production Share | Exports based on Prod Share | Exports by Port | Gravity Based Exports | Gravity Based Export Share | Ratio Gravity to Prod Shr |
|---|---|---|---|---|---|---|---|---|
| Illinois | IL | 6,637 | 13.1% | 3,074 | - | 2,663 | 11.4% | 0.87 |
| Iowa | IA | 5,849 | 11.6% | 2,710 | - | 2,622 | 11.2% | 0.97 |
| Minnesota | MN | 3,975 | 7.9% | 1,841 | - | 1,878 | 8.0% | 1.02 |
| Indiana | IN | 3,548 | 7.0% | 1,644 | - | 1,379 | 5.9% | 0.84 |
| North Dakota | ND | 3,238 | 6.4% | 1,500 | 239 | 1,777 | 7.6% | 1.18 |
| Nebraska | NE | 3,164 | 6.3% | 1,466 | - | 1,534 | 6.6% | 1.05 |
| Moissouri | MO | 3,032 | 6.0% | 1,404 | - | 1,423 | 6.1% | 1.01 |
| Ohio | OH | 2,881 | 5.7% | 1,334 | 239 | 1,111 | 4.7% | 0.83 |
| South Dakota | SD | 2,770 | 5.5% | 1,283 | - | 1,398 | 6.0% | 1.09 |
| Arkansas | AR | 1,829 | 3.6% | 847 | - | 987 | 4.2% | 1.17 |
| Kansas | KS | 1,825 | 3.6% | 845 | - | 904 | 3.9% | 1.07 |
| Mississippi | MS | 1,352 | 2.7% | 626 | - | 867 | 3.7% | 1.38 |
| Mishigan | MI | 1,165 | 2.3% | 540 | 239 | 475 | 2.0% | 0.88 |
| Wisconsin | WI | 1,156 | 2.3% | 536 | - | 488 | 2.1% | 0.91 |
| Kentucky | KY | 1,124 | 2.2% | 521 | - | 451 | 1.9% | 0.87 |
| North Carolina | NC | 1,011 | 2.0% | 468 | - | 405 | 1.7% | 0.86 |
| Georgia | GA | 950 | 1.9% | 440 | - | 446 | 1.9% | 1.01 |
| Tennessee | TN | 858 | 1.7% | 398 | - | 396 | 1.7% | 0.99 |
| Louisiana | LA | 829 | 1.6% | 384 | 13,374 | 616 | 2.6% | 1.60 |
| Texas | TX | 448 | 0.9% | 208 | 1,194 | 276 | 1.2% | 1.33 |
| Pennsylvania | PA | 369 | 0.7% | 171 | - | 128 | 0.5% | 0.75 |
| Alabama | AL | 363 | 0.7% | 168 | 239 | 197 | 0.8% | 1.17 |
| Florida | FL | 316 | 0.6% | 146 | - | 182 | 0.8% | 1.24 |
| Virginia | VA | 314 | 0.6% | 145 | 955 | 122 | 0.5% | 0.84 |
| Oklahoma | OK | 272 | 0.5% | 126 | - | 144 | 0.6% | 1.14 |
| Maryland | MD | 268 | 0.5% | 124 | - | 82 | 0.4% | 0.66 |
| South Carolina | SC | 260 | 0.5% | 120 | - | 103 | 0.4% | 0.86 |
| New York | NY | 190 | 0.4% | 88 | 239 | 69 | 0.3% | 0.78 |
| California | CA | 135 | 0.3% | 63 | 1,194 | 86 | 0.4% | 1.37 |
| Delaware | DE | 89 | 0.2% | 41 | - | 27 | 0.1% | 0.66 |
| Montana | MT | 78 | 0.2% | 36 | - | 48 | 0.2% | 1.31 |
| New Jersey | NJ | 67 | 0.1% | 31 | - | 22 | 0.1% | 0.70 |
| Washington | WA | 51 | 0.1% | 24 | 2,149 | 40 | 0.2% | 1.71 |
| Idaho | ID | 29 | 0.1% | 13 | - | 18 | 0.1% | 1.32 |
| Colorado | CO | 27 | 0.1% | 12 | - | 14 | 0.1% | 1.16 |
| New Mexico | NM | 19 | 0.0% | 9 | - | 11 | 0.0% | 1.20 |
| West Virginia | WV | 19 | 0.0% | 9 | - | 7 | 0.0% | 0.76 |
| Oregon | OR | 11 | 0.0% | 5 | 3,343 | 8 | 0.0% | 1.65 |
| Utah | UT | 5 | 0.0% | 3 | - | 3 | 0.0% | 1.18 |
| **Total** | | **50,524** | **100.0%** | **23,404** | **23,404** | **23,404** | **100.0%** | **1.00** |

**Table 2.** State exports of Wheat (WHT)

| State | | Production ($M) | Production Share | Exports based on Prod Share | Exports by Port | Gravity Based Exports | Gravity Based Export Share | Ratio Gravity to Prod Shr |
|---|---|---|---|---|---|---|---|---|
| North Dakota | ND | 2,604 | 16.8% | 1,096 | - | 1,078 | 16.6% | 0.98 |
| Kansas | KS | 2,194 | 14.2% | 923 | - | 778 | 11.9% | 0.84 |
| Washington | WA | 1,386 | 9.0% | 583 | 66 | 1,001 | 15.4% | 1.72 |
| Montana | MT | 1,368 | 8.8% | 576 | - | 704 | 10.8% | 1.22 |
| Idaho | ID | 739 | 4.8% | 311 | - | 400 | 6.1% | 1.28 |
| Minnesota | MN | 739 | 4.8% | 311 | 132 | 261 | 4.0% | 0.84 |
| Oklahoma | OK | 714 | 4.6% | 300 | - | 277 | 4.3% | 0.92 |
| South Dakota | SD | 582 | 3.8% | 245 | - | 216 | 3.3% | 0.88 |
| Colorado | CO | 536 | 3.5% | 226 | - | 227 | 3.5% | 1.01 |
| Oregon | OR | 455 | 2.9% | 192 | 3,420 | 347 | 5.3% | 1.81 |
| Texas | TX | 401 | 2.6% | 169 | 1,907 | 210 | 3.2% | 1.24 |
| Nebraska | NE | 379 | 2.5% | 160 | - | 133 | 2.0% | 0.83 |
| Ohio | OH | 368 | 2.4% | 155 | - | 69 | 1.1% | 0.45 |
| Illinois | IL | 333 | 2.1% | 140 | - | 76 | 1.2% | 0.54 |
| Missouri | MO | 303 | 2.0% | 127 | - | 92 | 1.4% | 0.73 |
| Michigan | MI | 292 | 1.9% | 123 | - | 60 | 0.9% | 0.49 |
| California | CA | 272 | 1.8% | 114 | - | 134 | 2.1% | 1.17 |
| Kentucky | KY | 227 | 1.5% | 96 | - | 48 | 0.7% | 0.51 |
| North Carolina | NC | 180 | 1.2% | 76 | - | 36 | 0.6% | 0.48 |
| Indiana | IN | 176 | 1.1% | 74 | - | 36 | 0.6% | 0.49 |
| Tennessee | TN | 165 | 1.1% | 69 | - | 44 | 0.7% | 0.63 |
| Arizona | AZ | 141 | 0.9% | 59 | - | 60 | 0.9% | 1.02 |
| Wisconsin | WI | 117 | 0.8% | 49 | - | 30 | 0.5% | 0.60 |
| Maryland | MD | 112 | 0.7% | 47 | - | 13 | 0.2% | 0.27 |
| Pennsylvania | PA | 104 | 0.7% | 44 | - | 14 | 0.2% | 0.33 |
| Virginia | VA | 81 | 0.5% | 34 | - | 13 | 0.2% | 0.37 |
| New York | NY | 79 | 0.5% | 33 | - | 10 | 0.2% | 0.30 |
| Alabama | AL | 74 | 0.5% | 31 | - | 24 | 0.4% | 0.78 |
| Arkansas | AR | 66 | 0.4% | 28 | - | 24 | 0.4% | 0.88 |
| Utah | UT | 59 | 0.4% | 25 | - | 27 | 0.4% | 1.08 |
| Georgia | GA | 39 | 0.3% | 16 | - | 10 | 0.2% | 0.63 |
| Delaware | DE | 36 | 0.2% | 15 | - | 4 | 0.1% | 0.24 |
| New Mexico | NM | 33 | 0.2% | 14 | - | 15 | 0.2% | 1.08 |
| South Carolina | SC | 28 | 0.2% | 12 | - | 6 | 0.1% | 0.49 |
| Wyoming | WY | 24 | 0.2% | 10 | - | 11 | 0.2% | 1.06 |
| Mississippi | MS | 20 | 0.1% | 8 | - | 8 | 0.1% | 1.01 |
| New Jersey | NJ | 14 | 0.1% | 6 | - | 1 | 0.0% | 0.23 |
| Iowa | IA | 11 | 0.1% | 4 | - | 3 | 0.0% | 0.71 |
| Nevada | NV | 9 | 0.1% | 4 | - | 4 | 0.1% | 0.97 |
| Louisiana | LA | 8 | 0.1% | 3 | 987 | 5 | 0.1% | 1.31 |
| **Total** | | **15,474** | **100.0%** | **6,512** | **6,512** | **6,512** | **100.0%** | **1.00** |

## 6. Conclusion

This analysis contributes to the...

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## References

Anderson, J.E., and E. van Wincoop. 2003. "Gravity with Gravitas: A Solution to the Border Puzzle." *American Economic Review*, 93(1): 170–192. doi:10.1257/000282803321455214.

Armington, P. 1969. "A Theory of Demand for Products Distinguished by Place of Production." *International Monetary Fund Staff Papers*, 16(1): 159–178. doi:10.2307/3866403.

Balistreri, E.J., and R.H. Hillberry. 2008. "The gravity model: An illustration of structural estimation as calibration." *Economic Inquiry*, 46(4): 511–527. doi:https://doi.org/10.1111/j.1465-7295.2007.00093.x.

Groskopf, J., and A. Silva. 2018. "The Evolution of Nebraska Corn Basis." https://cropwatch.unl.edu/2018/evolution-nebraska-corn-basis, *Crop Watch*, Sept 6, University of Nebraska–Lincoln, Institute of Agriculture and Natural Resources.

Larch, M., and Y. Yotov. 2016. "General Equilibrium Trade Policy Analysis with Structural Gravity." *CESifo Working Paper Series*, No. 6020: 1–84. http://dx.doi.org/10.2139/ssrn.2829263.

Nebraska Corn Board. 2023a. "Corn 101: Corn Uses: Feeding Livestock with Nebraska Corn." https://nebraskacorn.gov/corn-101/corn-uses/livestock/.

Nebraska Corn Board. 2023b. "You Asked, We Answered: Where All the Corn in Nebraska Goes." https://nebraskacorn.gov/cornstalk/sustainability/answered-where-does-all-the-corn-in-nebraska-go/.

U.S. Department of Agriculture. 2023a. "Annual Cash Receipts by Commodity." https://data.ers.usda.gov/reports.aspx?ID=17832, Economic Research Service, *Farm Income and Wealth Statistics*, February 7.

U.S. Department of Agriculture. 2023b. "State Agricultural Trade Data." https://www.ers.usda.gov/data-products/state-agricultural-trade-data/state-agricultural-trade-data/, Economic Research Service.

U.S. Department of Commerce. 2023. "USA Trade Online." https://usatrade.census.gov/, Bureau of the Census.

Yotov, Y.V., R. Piermartini, J.A. Monteiro, and M. Larch. 2016. *An Advanced Guide to Trade Policy Analysis: The Structural Gravity Model*. Geneva: UNCTAD. https://unctad.org/system/files/official-document/gds2016d3_en.pdf.