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Impacts of Chinese Tariff on World Soybean Markets

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China targeted U.S. soybeans, among other commodities, for its recent retaliatory tariff chiefly because of the sheer volume of its imports from the United States. We develop a theoretical and empirical spatial equilibrium trade model to analyze the effects of the 25% Chinese soybean tariff on the United States, China, and nine other major soybean trading regions. Both the United States and China incur welfare losses as a result of the tariff, but Brazil experiences a large net gain. The United States mitigates some of its losses by reallocating trade to other importers, but at a cost to smaller exporters such as Canada.

Key words: spatial equilibrium model, trade, welfare

Introduction

The ongoing trade war between the United States and several other countries has been simmering since the U.S. steel tariff and intellectual property dispute between China and the United States, which began in early 2018. As a result of this trade war, several trading partners retaliated by imposing tariffs on U.S. goods, particularly agricultural commodities. On July 6, 2018, China implemented retaliatory tariffs on imports of many U.S. commodities worth $50 billion, of which farm products, automobiles, and aquatic products account for $34 billion (People's Republic of China, Ministry of Finance, 2018). Chief among China's targeted commodities is soybeans, the leading U.S. agricultural commodity exported to China. The Chinese retaliatory tariff on U.S. soybeans is 25%. According to U.S. Department of Agriculture (2018d), the United States supplies 42% of Chinese soybean imports, accounting for 62% of U.S. exports (U.S. Department of Agriculture, 2018a). Soybean trade between the United States and China totaled $14 billion in 2017 (Good, 2018b), and consequently, a 25% soybean tariff would have dramatic effects on soybean markets in both countries. This tariff has already caused a sharp decline in U.S. soybean price, as well as an increase in Chinese soybean imports from Brazil (Good, 2018b,c), and these effects will only be exacerbated if the tariff continues.

The United States and China have significant market share (of exports by the United States and imports by China) in the world soybean market and can influence world price and trade volume, which impacts other exporting and importing countries' soybean markets. For example, China can divert its imports from the United States to U.S. competitors Brazil and Argentina, causing the price of soybeans from these other exporters to rise while the U.S. soybean price falls. The falling price of U.S. soybeans may lead other importers, such as the European Union, to purchase soybeans from the United States, which would allow the United States to regain some of the lost export market in China. Furthermore, small exporters, such as Canada, that typically sell to these other importers would lose much of their export market and therefore suffer the consequences of a trade war that they had no part in. These are just a few of the reallocations that could occur as a result of the Chinese

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tariff. Trade changes in each of these regions would also likely impact domestic prices, supply, and demand, which would reverberate in the world soybean market.

This study analyzes and quantifies the effects of the Chinese soybean tariff on U.S., Chinese, and other major importers' and exporters' soybean markets. To achieve this goal, we first develop a theoretical model and obtain analytical results of a tariff. Second, we construct an empirical spatial equilibrium model (SEM) of the world soybean market. The SEM, pioneered by Samuelson (1952) and popularized by Takayama and Judge (1971), is highly suited to study price, bilateral trade flow, supply, and demand impacts resulting from policy changes. Third, we run a baseline using this empirical model to solve for prices, production, consumption, and bilateral trade flows. Finally, we run an alternate scenario with the Chinese 25% tariff and compare the values of the endogenous variables to those in the baseline to quantify the impacts.

Literature Review

Economists have used the SEM extensively to study the impacts of trade policies. The SEM is particularly useful for examining how trade flows are reallocated among trade partners due to domestic and/or trade policies. The implementation of a 25% Chinese soybean tariff would affect the trade flows of several regions, and the SEM captures these ripple effects. However, with this capability comes a limitation: the model assumes that soybeans are a homogeneous commodity from all suppliers, and thus importers will buy soybeans based solely on the lowest purchase price. This may lead to trade reallocation results that do not strictly reflect real-world trade flows. For instance, the model may suggest that an entire export market will be lost as a result of the tariff, when in reality only a portion of the market is lost. This is because real-world trade decisions account for many noneconomic factors such as time lag, trade loyalty, contractual agreements, and political incentives, which are not readily amenable to modeling. For this reason, we considered several other models (nonspatial equilibrium, Armington, and gravity equation) and ascertained their suitability for analyzing the impacts of Chinese tariffs on the world soybean market, particularly the reallocation of trade flows.

The nonspatial equilibrium model only allows for a region's total exports or imports and does not determine bilateral trade flows between a pair of regions. Consequently, this model is unsuitable for quantifying trade diversion from one region to another due to policy changes. The Armington model removes the homogeneity assumption and differentiates the commodity based on country of origin but fails to recognize the trade reallocations that occur, the emergence of new markets, and the loss of old markets. The gravity model has become the workhorse in trade literature to model trade flows among regions, particularly after the pioneering study by Eaton and Kortum (2002) that used productivity shocks to capture comparative advantage. For example, Reimer and Li (2010) implemented this model to ascertain comparative advantage and trade cost effects on crop trade. The gravity model incorporates bilateral trade flows among trading partners and econometrically estimates the impacts of various policies and exogenous variables. The nature of econometric estimation, unlike the optimization in the SEM, does not allow the researchers to quantify trade flow reallocations. We must consider this trade-off when deciding which model to use. For this particular study, we decided that the benefits of determining trade reallocations outweighed the potential for over- or underestimating trade flow changes. Additionally, as described in the Data and Calibration section, in order to mitigate any exaggeration of trade reallocations, the model parameters are calibrated such that the base simulation results match real-world values.

Many studies have employed the SEM for policy analysis, and it is not possible to do justice reviewing all of these studies. Consequently, we briefly review some key studies. Within 1 year of Samuelson's (1952) initial work, Fox (1953) utilized the SEM to analyze the livestock feed market among various regions of the United States. More recently, Devadoss et al. (2005) used the SEM to analyze the effects of disputes between the United States and Canada on the world softwood lumber market. Apart from direct application of the SEM, many economists have made certain modifications to best fit the specific problem being studied. For example, Kawaguchi, Suzuki, and Kaiser (1997) modified the SEM in order to allow for several degrees of market competition in the Japanese dairy industry. Von Oppen and Scott (1976) developed a SEM by integrating location and interregional trade aspects to simultaneously determine optimal interregional trade as well as plant location and size.

Until the Uruguay Round, much of the trade policy analysis using the SEM incorporated specific tariffs. However, once the Uruguay Round converted all tariffs and quotas into equivalent ad valorem tariffs, it became imperative that ad valorem tariffs be incorporated into the SEM. Toward this goal, Devadoss (2013) made the ad valorem tariff model of Takayama and Judge (1971) operational. These studies have shown that when an ad valorem tariff is included in the model, the quasi-welfare function of the traditional SEM is no longer strictly concave. Consequently, instead of maximizing the quasi-welfare function, they propose maximizing the net revenue function. Furthermore, Devadoss demonstrated that optimization of the primal or dual approach can be also readily undertaken using the mixed complementarity problem (MCP). The MCP solves the system of equations which are the first-order conditions of either the primal or dual approach, which yield identical first-order conditions. In this study we employ the MCP approach for the empirical analysis.

Within months of the initial tariff threats, multiple reports appeared in *Choices* magazine, spearheaded by Marchant and Wang (2018); the popular press; and Farmdoc articles, emphasizing the importance of this issue and the severity of the impacts of Chinese tariffs. The soybean tariff has been of particular interest because of the sheer volume of soybean trade between the United States and China. Several studies (Durisin and Dodge, 2018; Good, 2018b,a,c; Plume, 2018) reported qualitative impacts of the Chinese tariff on U.S. and Chinese soybean markets. In addition to these reports, several empirical studies have estimated the impacts of the Chinese soybean tariff. For example, Zheng et al. (2018) utilized the Global Simulation Model and Taheripour and Tyner (2018) used the Global Trade Analysis Project model to study the Chinese tariff. In the results section, we compare the results of these studies with our own to provide validity to our modeling framework and findings.

The contributions of this study to the literature lie in the analytical results of the theoretical model and the ability of the SEM to capture bilateral trade flows and reallocation of trade arising from policy changes. The theoretical analysis clearly shows the adverse effects of the Chinese tariff on the U.S. soybean market, the advantages accrued to Brazil, and the mitigation of U.S. losses by trade reallocation. Applying the empirical SEM to this theoretical framework accurately quantifies the effects of the Chinese tariff on price, production, consumption, and bilateral trade flows. We also compute the welfare effects of this tariff using changes in producer surplus, consumer surplus, and tariff revenue. The findings of our study, in conjunction with current literature, are valuable to soybean growers, agribusiness firms operating in the domestic and export markets, and policy makers.

Theoretical Analysis

The supply, demand, and trade flows of a many-region ($i, j = 1, \ldots n$) model can be succinctly summarized by the following market-clearing and spatial arbitrage conditions:

$$S_i(P_i^P) = D_i(P_i^C) + \sum_{j \neq i}^{n} X_{ij}, \; \forall\, i, \tag{1}$$

$$S_j(P_j^P) + \sum_{i \neq j}^{n} X_{ij} = D_j(P_j^C), \; \forall\, j, \tag{2}$$

$$P_j^C = P_i^P - s_i + t_{ij} + \tau_{ij}, \; \forall\, i, j, \tag{3}$$

where $S_i(\bullet)$ is the supply function in region i, $D_i(\bullet)$ is the demand function in i, P_i^P is producer price in i, P_i^C is consumer price in i, X_{ij} is volume of trade from region i to region j, s_i is subsidy provided by i, t_{ij} is transport costs from i to j, and τ_{ij} are tariffs levied by j on imports from i. Equation (1) states that for an exporting region i, supply equals domestic demand plus exports to all other regions. Equation (2) indicates that for an importing region j, supply plus imports from all other regions equal domestic demand. In addition to these market-clearing conditions, the model also incorporates the spatial arbitrage of prices between any pair of regions. Equation (3) captures this spatial arbitrage, wherein consumer price in the importing region j is equal to producer price in the exporting region i minus production subsidy provided by i, plus transport costs incurred in moving the commodity from i to j, and tariffs imposed by j on imports coming from i.

This n-region model contains $n + n^2$ equations (i.e., n market-clearing conditions for exporting and importing regions plus n^2 price linkage equations). Since obtaining analytical results is not plausible given this large system of equations, we simplify the model into four regions: two exporting—the United States (U) and Brazil (B)—and two importing—China (C) and the European Union (E). This stylized model allows us to examine how the Chinese tariff causes China to divert its imports from the United States to Brazil and the United States to export more to the European Union to mitigate the export loss to China. However, our empirical model encompasses 11 regions—five exporting and six importing—to more accurately model the world soybean market. These regions are delineated in the empirical analysis section.

In Appendix A, we present in detail how the four regions' market-clearing conditions and the corresponding spatial-arbitrage conditions are simplified into a four-region model consisting of the following market-clearing conditions with embedded spatial arbitrage:

$$(4) \qquad S_U(P_U^P) = D_U(P_U^P - s_U + t_{UU}) + X_{UC} + X_{UE},$$

$$(5) \qquad S_B(P_U^P - s_U + t_{UC} + \tau_{UC} - t_{BC}) = D_B(P_U^P - s_U + t_{UC} + \tau_{UC} - t_{BC} + t_{BB}) + X_{BC} + X_{BE},$$

$$(6) \qquad S_C(P_U^P - s_U + t_{UC} + \tau_{UC} + s_C - t_{CC}) + X_{UC} + X_{BC} = D_C(P_U^P - s_U + t_{UC} + \tau_{UC}),$$

$$(7) \qquad S_E(P_U^P - s_U + t_{UE} - t_{EE}) + X_{UE} + X_{BE} = D_E(P_U^P - s_U + t_{UE}).$$

Equation (4) states that U.S. soybean supply, which is a function of U.S. producer price P_U^P, is equal to U.S. domestic demand plus exports to China X_{UC} and exports to the European Union X_{UE}. The domestic demand is a function of consumer price P_U^C, equal to producer price minus U.S. subsidy s_U plus internal transport cost t_{UU}.

Equation (5) states that Brazilian soybean supply, a function of Brazilian producer price P_B^P, is equal to Brazil's domestic demand, a function of Brazilian consumer price P_B^C, plus exports to China X_{BC} and the European Union X_{BE}. Brazilian producer price P_B^P is equal to U.S. producer price minus U.S. subsidy plus transport cost from the United States to China t_{UC} plus Chinese tariff τ_{UC} minus transport cost from Brazil to China t_{BC}. This price linkage equation is derived by combining the price linkages

$$(8) \qquad P_C^C = P_U^P - s_U + t_{UC} + \tau_{UC} \text{ and}$$

$$(9) \qquad P_C^C = P_B^P + t_{BC}.$$

Equation (8) indicates that market price in China P_C^C is equal to U.S. producer price minus U.S. subsidy plus transport cost from the United States to China and tariff imposed by China. Equation (9) indicates that market price in China P_C^C is equal to producer price in Brazil plus transport cost from Brazil to China. We consider soybeans as a homogeneous product, so the market price in China is the same for soybeans imported from either the United States or Brazil. Equating these two price linkages and solving for P_B^P results in $P_B^P = P_U^P - s_U + t_{UC} + \tau_{UC} - t_{BC}$.

Brazilian consumer price $P_B^C = P_B^P + t_{BB}$, where t_{BB} is the internal transport cost, and substituting $P_B^P = P_U^P - s_U + t_{UC} + \tau_{UC} - t_{BC}$ results in the argument in the Brazilian demand function.

Equation (6) shows that Chinese supply plus imports from the United States and Brazil equal Chinese demand, a function of Chinese consumer price P_C^C. Chinese producer price is $P_C^P = P_C^C + s_C - t_{CC}$, where s_C is the Chinese production subsidy and t_{CC} is the internal transport cost in China, and substituting for $P_C^C = P_U^P - s_U + t_{UC} + \tau_{UC}$ in this equation results in the argument in the Chinese supply function.

Finally, equation (7) asserts that EU supply plus imports from the United States and Brazil is equal to EU demand, a function of EU consumer price $P_E^C = P_U^P - s_U + t_{UE}$, where t_{UE} is transport cost from the United States to the European Union. EU supply is a function of EU producer price $P_E^P = P_E^C - t_{EE}$, and substituting for P_E^C results in the argument in the EU supply function. [1]

Totally differentiating the system of four equations (4)–(7) and arranging them in matrix form $\mathbf{Ax} = \mathbf{b}$ gives the following:

$$(10)\quad \begin{bmatrix} \left(\frac{\partial S_U}{\partial P_U^P} - \frac{\partial D_U}{\partial P_U^C}\right) & -1 & -1 & 0 \\ \left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C}\right) & 0 & 0 & -1 \\ \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C}\right) & 1 & 0 & 1 \\ \left(\frac{\partial S_E}{\partial P_E^P} - \frac{\partial D_E}{\partial P_E^C}\right) & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} dP_U^P \\ dX_{UC} \\ dX_{UE} \\ dX_{BC} \end{bmatrix} = \begin{bmatrix} -\frac{\partial D_U}{\partial P_U^C} ds_U \\ \left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C}\right) ds_U - \left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C}\right) d\tau_{UC} \\ \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C}\right) ds_U - \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C}\right) d\tau_{UC} - \frac{\partial S_C}{\partial P_C^P} ds_C \\ \left(\frac{\partial S_E}{\partial P_E^P} - \frac{\partial D_E}{\partial P_E^C}\right) ds_U \end{bmatrix},$$

where the determinant of the coefficient matrix $\boldsymbol{A}$ is negative:

$$(11)\quad |\mathbf{A}| = -\left[\left(\frac{\partial S_U}{\partial P_U^P} - \frac{\partial D_U}{\partial P_U^C}\right) + \left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C}\right) + \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C}\right) + \left(\frac{\partial S_E}{\partial P_E^P} - \frac{\partial D_E}{\partial P_E^C}\right)\right] < 0.$$

This determinant, consisting of the slopes of excess supply/demand, which in turn depends on each region's supply and demand conditions, indicates that the following comparative static results rely heavily on the magnitude of supply and demand elasticities in all regions.[2] Applying Cramer's Rule to the system of equations (10), we can solve for changes in the four endogenous variables in response to policy variables s_U, s_C, and τ_{UC}. However, since the focus of the analysis is on the effect of the Chinese tariff τ_{UC}, we present the comparative static analysis of only τ_{UC} on key endogenous variables. The comparative static results are presented below.

$$(12)\quad \frac{\partial X_{UC}}{\partial \tau_{UC}} = \frac{\left[\left(\frac{\partial S_U}{\partial P_U^P} - \frac{\partial D_U}{\partial P_U^C}\right) + \left(\frac{\partial S_E}{\partial P_E^P} - \frac{\partial D_E}{\partial P_E^C}\right)\right]\left[\left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C}\right) + \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C}\right)\right]}{|\mathbf{A}|} < 0.$$

In equation (12), the numerator is positive and the denominator, $|\mathbf{A}|$, is negative, indicating that the Chinese tariff reduces soybean imports from the United States. The rationale for this result is that the Chinese tariff will make U.S. soybeans more expensive; consequently, Chinese imports of U.S. soybeans fall. The magnitude of change is determined by the excess supply/demand elasticities of the United States and the European Union multiplied by the excess supply/demand elasticities of Brazil and China, weighted by the value of the determinant $|\mathbf{A}|$, which captures the excess supply/demand elasticities of all four regions. Thus, changes in Chinese imports depend on the market conditions not only in China and the United States, but also in Brazil and the European Union. These interlinkages

[1] The system of four equations in (4)–(7) contains five endogenous variables: P_U^P, X_{UC}, X_{UE}, X_{BC}, X_{BE}. Consequently, to solve the system, we eliminate X_{BE}, which allows us to analytically show that China reallocates soybean imports from the United States to Brazil and that the United States recoups some of the lost exports to China by redirecting its sales to the European Union.

[2] Note that the slopes in determinant $|\mathbf{A}|$ can be converted into elasticities.

are explicitly captured *only* by the SEM:

$$(13)\qquad \frac{\partial P_U^P}{\partial \tau_{UC}} = \frac{\left[\left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C}\right) + \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C}\right)\right]}{|\mathbf{A}|} < 0.$$

Equation (13) shows that the Chinese tariff causes a decrease in U.S. producer price. This is because the Chinese tariff reduces Chinese imports from the United States, as demonstrated in equation (12), resulting in more availability to sell in the U.S. domestic market and thus lowering the U.S. price. The magnitude of this decrease depends on the value of the excess supply/demand elasticities of Brazil and China, weighted by the value of determinant $|\mathbf{A}|$:

$$(14)\qquad \frac{\partial X_{UE}}{\partial \tau_{UC}} = \frac{-\left(\frac{\partial S_E}{\partial P_E^P} - \frac{\partial D_E}{\partial P_E^C}\right)\left[\left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C}\right) + \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C}\right)\right]}{|\mathbf{A}|} > 0.$$

Although the Chinese tariff is only intended to limit imports from the United States, equation (14) reveals a spillover effect: U.S. exports to the European Union increase. This is just one of the trade reallocations highlighted in the introduction and is a result of the decreased U.S. producer price and additional U.S. soybeans available from lost exports to China. Here, the magnitude depends on the excess demand elasticity of the European Union multiplied by the excess supply/demand elasticities of China and Brazil, weighted by $|\mathbf{A}|$:

$$(15)\qquad \frac{\partial X_{BC}}{\partial \tau_{UC}} = \frac{-\left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C}\right)\left[\left(\frac{\partial S_U}{\partial P_U^P} - \frac{\partial D_U}{\partial P_U^C}\right) + \left(\frac{\partial S_E}{\partial P_E^P} - \frac{\partial D_E}{\partial P_E^C}\right)\right]}{|\mathbf{A}|} > 0.$$

Finally, the change in Brazil's exports to China in response to the Chinese tariff is positive, because the decrease in U.S. exports to China caused by the tariff leads to more opportunities for Brazil to export to China. Thus, Brazilian soybean producers benefit from the trade war between the United States and China. The magnitude of this change is dependent on the excess supply elasticity of Brazil multiplied by the excess supply/demand elasticities of the United States and the European Union, weighted by $|\mathbf{A}|$.

Using the above results, the comparative statics for several other variables (such as supply and demand in each region) can be obtained. For example, the effect of the Chinese tariff on U.S. demand is

$$(16)\qquad \frac{\partial D_U}{\partial \tau_{UC}} = \frac{\partial D_U}{\partial P_U^C}\frac{\partial P_U^C}{\partial P_U^P}\frac{\partial P_U^P}{\partial \tau_{UC}} = \frac{\partial D_U}{\partial P_U^C}\frac{\left[\left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C}\right) + \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C}\right)\right]}{|\mathbf{A}|} > 0.$$

Equation (16) reveals that demand in the United States increases as a result of the Chinese tariff. The rationale for this result is that the decrease in U.S. producer price, equation (13), causes consumer price to decrease and domestic demand to rise. The effect of the Chinese tariff on U.S. supply is

$$(17)\qquad \frac{\partial S_U}{\partial \tau_{UC}} = \frac{\partial S_U}{\partial P_U^P}\frac{\partial P_U^P}{\partial \tau_{UC}} = \frac{\partial S_U}{\partial P_U^P}\frac{\left[\left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C}\right) + \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C}\right)\right]}{|\mathbf{A}|} < 0.$$

The Chinese tariff reduces U.S. supply as it lowers U.S. producer price, which indicates that the decrease in U.S. exports to China shown in equation (12) dominates both the increase in exports to the European Union (equation 14) and the increase in domestic demand (equation 16). The effect of the Chinese tariff on Chinese soybean demand is[3]

$$\frac{\partial D_C}{\partial \tau_{UC}} = -\frac{\partial D_C}{\partial P_C^C}\left(\frac{\left[\left(\frac{\partial S_U}{\partial P_U^P} - \frac{\partial D_U}{\partial P_U^C}\right) + \left(\frac{\partial S_E}{\partial P_E^P} - \frac{\partial D_E}{\partial P_E^C}\right)\right]}{|\mathbf{A}|}\right) < 0. \tag{18}$$

The tariff increases Chinese consumer price, causing Chinese demand to fall. The effect of the Chinese tariff on supply of the U.S. competitor (i.e., Brazil) is

$$\frac{\partial S_B}{\partial \tau_{UC}} = -\frac{\partial S_B}{\partial P_B^P}\left(\frac{\left[\left(\frac{\partial S_U}{\partial P_U^P} - \frac{\partial D_U}{\partial P_U^C}\right) + \left(\frac{\partial S_E}{\partial P_E^P} - \frac{\partial D_E}{\partial P_E^C}\right)\right]}{|\mathbf{A}|}\right) > 0. \tag{19}$$

Equation (19) shows that Brazilian supply expands because China diverts its imports from the United States to Brazil. Consequently, Brazilian exports rise, leading to a higher soybean price and supply in Brazil. The comparative statics for Chinese supply, Brazilian demand, and EU supply and demand can also be obtained but are not presented here in the interest of space consideration.

Empirical Analysis

We implement the theoretical model developed in the previous section using the SEM through either the primal, dual, or MCP approach. The primal approach maximizes the quasi-welfare function, subject to market-clearing conditions, by optimizing over quantities. The dual approach minimizes cost, subject to (i) price linkages, (ii) supply price-cost of production, and (iii) demand price-willingness to pay, by optimizing over prices. Devadoss (2013) shows that the first-order conditions of both the primal and dual problems lead to identical Kuhn–Tucker conditions and economic interpretations. The MCP approach solves the system of complementary-slackness equations associated with these Kuhn–Tucker conditions and does not require an objective function. Although the MCP approach is scantly used in the literature, it is relatively simpler to implement empirically. For this reason, we employ the MCP and use GAMS software to solve the model. The MCP equations used in the empirical model are

$$MP_i^C \geq \alpha_i - \beta_i Q_i^D, \ \forall\, i, \tag{20}$$

where MP_i^C is the market demand price in i, α_i is the inverse demand intercept of i, β_i is the inverse demand slope of i, and Q_i^D is the quantity demanded in i. Equation (20) requires the market demand price to be on or above the demand curve. That is, market demand price is greater than (when demand quantity is zero or equal to (when demand quantity is positive) the willingness to pay.

$$\gamma_i + \theta_i Q_i^S \geq MP_i^P, \ \forall\, i, \tag{21}$$

where γ_i is the inverse supply intercept of i, θ_i is the inverse supply slope of i, Q_i^S is the quantity supplied in i, and MP_i^P is the market supply price in i. Equation (21) shows that the market supply price must be on or below the supply curve. Therefore, the market supply price must be less than (when supply quantity is zero) or equal to (when supply quantity is positive) the marginal cost.

$$t_{ij} \geq MP_j^C * \frac{1}{1+\tau_{ij}} - MP_i^P, \ \forall\, i, j, \tag{22}$$

where t_{ij} is the transport cost from region i to region j, and τ_{ij} is the ad valorem tariff levied by region j on imports from region i. Equation (22) is a price linkage equation that confines market demand price (including ad valorem tariff) in j minus the market supply price in i to be less than

[3] Appendix A shows the derivations of equations (18) and (19).

or equal to transport costs. This restricts exporters from charging a price that is less than the sum of their own producer price in i and the cost of transport from i to j. If the price charged in the importing region is more than the producer price in the exporting region plus transport cost, then profit opportunities exist, which will entice other exporters to sell to this importing region until the profit opportunities are exhausted.

$$\sum_{i=1}^{n} X_{ij} \geq Q_i^D, \ \forall\ j. \tag{23}$$

Equation (23) shows that demand must be met by domestic supply and foreign imports so that there is no excess demand; otherwise, price will increase until the supply satisfies the demand.

$$Q_i^S \geq \sum_{j=1}^{n} X_{ij}, \ \forall\ i. \tag{24}$$

Equation (24) demonstrates that the quantity supplied should be at least as much as the quantity sold domestically and in foreign markets. As explained above, equations (20)–(24) hold with equality for interior solutions. It is worth noting that equations (20)–(24) are equivalent to the theoretical model presented in equations (4)–(7), as equations (20) and (21) are captured in the supply and demand functions in equations (4)–(7), the price linkage equation (22) is embedded in equations (4)–(7), equation (23) is the market-clearing condition for importers given in equations (6) and (7), and equation (24) is the market-clearing condition for exporters shown in equations (4) and (5). More generally, equations (20)–(24) are directly comparable to equations (1)–(3) with linear supply and demand functions expressed in general functional form.

The system of equations (20)–(24) is solved simultaneously using the parameters ($\alpha_i, \beta_i, \gamma_i$, and θ_i) and exogenous variables (t_{ij} and τ_{ij}) to obtain the values of the endogenous variables (MP_i^C, MP_i^P, Q_i^D, Q_i^S, and X_{ij}). We solve the system once with $\tau_{UC} = 0$ to find baseline values and then again with $\tau_{UC} = 0.25$ to find the tariff scenario values. The empirical model includes 11 regions: the United States, Brazil, Argentina, Paraguay, Canada, China, Mexico, the European Union, Japan, Taiwan, and the rest of the world (ROW). Therefore, there are a total of 165 equations: 44 demand price, supply price, demand quantity, and supply quantity conditions plus 121 price linkage equations.

After solving for baseline and tariff scenarios for the values of endogenous variables, we compute changes in producer surplus, consumer surplus, tariff revenues, and net surplus. Change in producer surplus, ΔPS, for region i is calculated by integrating the supply function between producer prices in the baseline and tariff scenarios:[4]

$$\Delta PS = \int_{P_i^P}^{P_i^{P,\tau}} \Gamma_i + \Theta_i P dP, \tag{25}$$

where Γ_i and Θ_i are the supply intercept and slope in region i, and P_i^P and $P_i^{P,\tau}$ are region i's producer prices in the baseline and tariff scenarios, respectively. The change in producer surplus will be positive if $P_i^{P,\tau}$ is above P_i^P and negative if $P_i^{P,\tau}$ is below P_i^P. Similarly, the change in consumer surplus, ΔCS, is computed using

$$\Delta CS = \int_{P_i^{C,\tau}}^{P_i^C} A_i - B_i P dP, \tag{26}$$

[4] Note that the supply and demand functions in Q-P space in equations (25) and (26) correspond to the supply and demand functions in P-Q space in equations (20) and (21).

where A_i and B_i are the demand intercept and slope in region i, and P_i^C and $P_i^{C,\tau}$ are region i's consumer prices in the baseline and tariff scenarios, respectively. Change in consumer surplus is positive when P_i^C is above $P_i^{C,\tau}$ and negative when P_i^C is below $P_i^{C,\tau}$. Ad valorem tariff revenue is computed as quantity of imports times CIF price times tariff rate:

$$TR = \left(\sum_{i \neq j}^{n} X_{ij} \right) \times \left(\left(MP_i^P + t_{ij} \right) \times \tau_{ij} \right) \tag{27}$$

Tariff revenue is strictly nonnegative. Net surplus is the sum of changes in producer surplus, consumer surplus, and tariff revenue, $NS = \Delta PS + \Delta CS + TR$, and can be positive or negative.

Data and Calibration

The data needed for empirically implementing the model are production and consumption quantities, domestic prices, transport costs, supply and demand elasticities, and realized trade flows. Production and consumption data for each region came from U.S. Department of Agriculture (2018e). We collected these quantity data for the years 2015–2018, and used the average to smooth out unduly upward and downward swings in the data. Region-level price data are not available from a single source and, consequently, were obtained from several sources, including the U.S. Department of Agriculture (2018b, Table 29) for the United States, Brazil, and Argentina, the U.S. Department of Agriculture (2018c) for Paraguay, and the Grain Farmers of Ontario (2018) for Canada. Domestic prices for China, Mexico, the European Union, Japan, and Taiwan were estimated using the average transport cost from regions they are importing from and world price. The average world price for 2015–2018 is from Macrotrends (2018) and is also used as the domestic price for ROW. Japan, the United States, and China provide production subsidies, which were collected from Hudson (2018).

Transport costs were obtained using data from WorldFreightRates (2018) for an average soybean price of \$401/metric ton with a 10,000 metric ton (MT) load. For regions with multiple ports, calculations were made based on the shortest port-to-port distance. For landlocked Paraguay, transport costs include costs from Asunción, Paraguay, to Buenos Aires, Argentina, plus additional costs to the import destinations. Furthermore, we ensured transport costs were such that there were no trans-shipments through a third region.

Supply and demand elasticities for most of the regions came from FAPRI (2018). U.S. and ROW elasticities were collected from Devadoss et al. (1989), and Mexican elasticities were obtained from Reimer, Zheng, and Gehlhar (2012). Additionally, Paraguay's elasticities are constructed using Argentinian elasticities because of their close proximity and similar cultivation practices.

To construct the supply equations, we utilize the supply elasticities, prices, and quantities. The slope, Θ, of a linear supply function can be obtained from the elasticity formula $\varepsilon = \frac{dQ_S}{dP}\frac{P}{Q_S}$ as[5]

$$\frac{dQ_S}{dP} = \varepsilon \frac{Q_S}{P} = \Theta. \tag{28}$$

Using Θ, the intercept, Γ, is computed using the supply function $Q_S = \Gamma + \Theta P$ as

$$\Gamma = Q_S - \Theta P. \tag{29}$$

Thus, the constructed supply function is $Q_S = \hat{\Gamma} + \hat{\Theta} P$. Following a similar approach, we construct the demand function as $Q_D = \hat{A} - \hat{B} P$. We then convert these to the inverse supply and demand functions $P^P = \hat{\gamma} + \hat{\theta} Q^S$ and $P^C = \hat{\alpha} - \hat{\beta} Q^D$, which are used in the empirical analysis. Running a baseline scenario with these supply and demand functions for equations (20), (21), and (22)–(24) generates supply and demand quantities that are close to, but do not replicate, the actual quantities.

[5] For China, Japan, and the United States, we accounted for subsidies when constructing their supply functions.

Table 1. Inverse Supply and Demand Functions

	Supply Function	Demand Function
USA	$P^P = -857.112 + 0.011Q_S$	$P^C = 2007.455 - 0.029Q_D$
Brazil	$P^P = -658.059 + 0.009Q_S$	$P^C = 2457.750 - 0.046Q_D$
Argentina	$P^P = -741.625 + 0.021Q_S$	$P^C = 1745 - 0.029Q_D$
Paraguay	$P^P = -711.875 + 0.109Q_S$	$P^C = 1675 - 0.341Q_D$
Canada	$P^P = -773.5 + 0.162Q_S$	$P^C = 1820 - 0.545Q_D$
China	$P^P = -1373.444 + 0.135Q_S$	$P^C = 2478 - 0.019Q_D$
Mexico	$P^P = -1455.128 + 4.268Q_S$	$P^C = 2424.876 - 0.415Q_D$
EU	$P^P = -1302 + 0.685Q_S$	$P^C = 2384.562 - 0.119Q_D$
Japan	$P^P = -5739.980 + 24.799Q_S$	$P^C = 1452.5 - 0.3Q_D$
Taiwan	$P^P = -2368.689 + 484.511Q_S$	$P^C = 1811.333 - 0.555Q_D$
ROW	$P^P = -1568.842 + 0.110Q_S$	$P^C = 1594.667 - 0.029Q_D$

This is because the elasticities obtained from the literature are based on econometric estimations involving a disturbance term, data inaccuracies, specification problems, etc. To overcome this problem, Paris, Drogué, and Anania (2009) developed an approach to calibrate the parameters such that solved trade flows exactly match the realized trade flows. Therefore, for this calibration we need data on realized trade flows, which we computed using the export quantity data from the U.S. Department of Agriculture (2018e) and 2016 bilateral export destination percentages from Simoes and Hidalgo (2018). The inverse supply and demand functions constructed using these calibrated parameters are given in Table 1.

Simulation and Results

The inverse supply and demand equations and transport costs are used to run the baseline and tariff scenarios. The baseline simulation assumes free trade in the world soybean market and replicates the actual supply and demand quantities. The alternative tariff scenario results are compared with those of the baseline scenario to examine the impacts of this tariff on prices, production, consumption, and trade flows. We also undertake a welfare analysis of this tariff by computing change in producer surplus, consumer surplus, and overall welfare. Table 2 presents the effects of the Chinese tariff on prices, production, consumption, and welfare. Table 3 reports the baseline trade flows from exporters (rows) to importers (columns) and changes in trade flows caused by the Chinese tariff. The percentage change is calculated using $(X_{ij}^{\tau} - X_{ij})/X_{ij}$, where X_{ij} is the baseline trade flow from i to j and X_{ij}^{τ} is the tariff scenario trade flow from i to j. If the baseline trade flow X_{ij} is zero (i.e., region i does not export to region j), then percentage change cannot be computed. In this case, we report only the changes in trade flows in thousands of metric tons.

We discuss the results of Tables 2 and 3 in tandem because of the symbiotic relationships among price, supply, demand, and trade flows. The simulation results in both tables confirm that the quantitative impacts of the Chinese tariff are in line with the directional impacts derived in the theoretical analysis for prices, supply, demand, and trade flows. The producer and consumer prices are the same for all regions, except for China, Japan, and the United States, because demand and supply functions are measured at the same market level. Producer and consumer prices are different in China, Japan, and the United States because of the production subsidies provided by these countries, which create a wedge between these two prices.[6]

[6] Note that baseline trade flows are not exactly representative of realized trade flows and are instead the optimal trade flows solved by the model. This is because realized trade flows account for noneconomic factors such as political motives and prearranged contractual agreements.

Table 2. Baseline Values, Tariff Scenario Percentage Changes, and Surplus Changes

	Producer Price		Consumer Price		Production		Consumption		Surplus		
Country/ Region	Baseline ($/MT)	Change (%)	Baseline ($/MT)	Change (%)	Baseline (1,000 MT)	Change (%)	Baseline (1,000 MT)	Change (%)	Producer ($ billions)	Consumer ($ billions)	Net ($ billions)
USA	415.46	−11.92	394.16	−12.56	113,752	−3.96	55,631	3.07	−5.52	2.80	−2.72
Brazil	364.24	7.70	364.24	7.70	113,589	2.74	45,511	−1.34	3.23	−1.27	1.96
Argentina	362.28	7.37	362.28	7.37	52,567	2.42	47,680	−1.93	1.42	−1.26	0.16
Paraguay	353.73	7.24	353.73	7.24	9,776	2.40	3,875	−1.94	0.25	−0.10	0.15
Canada	394.75	−1.98	394.75	−1.98	7,211	−0.67	2,615	0.55	−0.06	0.02	−0.04
China	596.53	4.70	414.53	6.77	13,244	1.57	108,604	−1.36	0.37	−3.03	−2.66
Mexico	447.28	−11.07	447.28	−11.07	446	−2.60	4,765	2.50	−0.02	0.24	0.22
EU	434.15	−5.81	434.15	−5.81	2,535	−1.45	16,390	1.29	−0.06	0.42	0.35
Japan	1773.43	−2.78	414.05	−11.89	248	−0.80	3,461	4.74	−0.01	0.17	0.16
Taiwan	414.91	−11.93	414.91	−11.93	6	−1.78	2,516	3.55	−0.0002	0.13	0.13
ROW	422.27	−5.46	422.27	−5.46	18,101	−1.16	40,427	1.97	−0.42	0.94	0.52
World	n/a	n/a	n/a	n/a	331,475	0.006	331,475	0.006	−0.81	−0.94	−1.75

Table 3. Baseline/Tariff Scenario Trade Flows with Baseline Quantities (1,000 MT) and Impacts (Percentage or 1,000 MT)

Country/ Region	USA	Brazil	Argentina	Paraguay	Canada	China	Mexico	EU	Japan	Taiwan	ROW
USA	55,631					51,292	4,320	0	0	2,510	0
	(3.069%)					(-100%)	(3.030%)	(+14,104)	(+3,379)	(3.557%)	(+27,380)
Brazil		45,511				44,068		9,259	3,213		11,538
		(-1.340%)				(62.939%)		(-100%)	(-100%)		(-100%)
Argentina			47,680			0					4,887
			(-1.930%)			(+7,078)					(-100%)
Paraguay				3,875		0					5,902
				(-1.939%)		(+6,212)					(-100%)
Canada					2,615	0		4,596			
					(0.549%)	(+4,534)		(-100%)			
China						13,244					
						(1.568%)					
Mexico							446				
							(-2.602%)				
EU								2,535			
								(-1.452%)			
Japan									248		
									(-0.800%)		
Taiwan										6	
										(-1.775%)	
ROW						0					18,101
Change						(+4,049)					(-23.527%)

Notes: Numbers in parentheses indicate change (Percentage or 1,000 MT).

The tariff increases China's consumer price by 6.77% and, in response to this change in consumer price (through the domestic price linkage equation), the producer price increases by 4.70%. The higher consumer price decreases consumption by 1.36%, while the higher producer price expands production by 1.57%. China's price and quantity changes decrease consumer surplus by \$3.03 billion but increase producer surplus by \$370 million, resulting in a net welfare loss of \$2.66 billion.[7] Because of the 2% tariff, China stops importing from the United States and diverts all of its imports of U.S. soybeans to other regions: Brazil, Argentina, Paraguay, Canada, and ROW (see Table 3). To put the surplus changes into perspective, China's \$3.03 billion decrease in consumer surplus equates to 6.73% of Chinese soybean consumption value, in spite of increased imports from Brazil, Argentina, Paraguay, Canada, and ROW. China's producer surplus increase is 4.68% of total value of production. However, it is important to note that China's total value of consumption is far greater than the total value of production, and these percentage changes, though similar, are misleading. That is, 6.73% of China's consumption value is much larger than 4.68% of its production value.

Since the United States is exporting less to China, its producer and consumer prices decline by 11.92% and 12.56%, respectively, because more is available for domestic sales. The drop in U.S. prices cause a 3.96% decrease in production and a 3.07% increase in consumption. Table 3 shows that the United States mitigates some of its export losses to China by increasing exports to Mexico, the European Union, Japan, Taiwan, and ROW. Regardless of these trade reallocations, however, welfare in the United States suffers more than in any other country as a result of the Chinese tariff, with producer surplus falling by \$5.52 billion, consumer surplus rising by \$2.80 billion, and net surplus declining by \$2.72 billion. The \$5.52 billion decrease in U.S. producer surplus is 11.86% of the total value of U.S. soybean production, while the \$2.80 billion increase in U.S. consumer surplus is 12.77% of the total value of U.S. soybean use. Taheripour and Tyner (2018) used the GTAP model to evaluate the impacts of Chinese tariffs on many commodities. Their results for the soybean market show that U.S. and Chinese net surplus declines by −\$2.55 billion and −\$2.55 billion, respectively.[8] These results corroborate our findings of U.S. and Chinese net surplus changes of −\$2.72 billion and −\$2.66 billion, respectively.

Brazil is the second largest soybean producer in the world;[9] as a result of the tariff, China reallocates much of its imports from the United States to Brazil. Specifically, Brazil's exports to China rise by 62.94%, which causes price in Brazil to increase by 7.70%. As a consequence, Brazil experiences a 2.74% increase in production and a \$3.23 billion increase in producer surplus, which is 7.81% of the value of production. To meet the Chinese demand, Brazil diverts 100% of its exports from the European Union, Japan, and ROW to China. The price increase causes Brazilian demand to decrease by 1.34%, resulting in a \$1.27 billion loss in consumer surplus which is 7.66% of the value of consumption. Overall, Brazil amasses \$1.96 billion in welfare and therefore benefits the most by virtue of this trade war. The aggregate ROW region has the second largest gain from the Chinese tariff with a \$520 million increase in net surplus, but these benefits are spread among many regions. This increase in welfare is caused by the 5.46% decrease in consumer and producer prices, which increase consumption by 1.97% and consumer surplus by \$940 million. ROW production falls by 1.16%, and producer surplus accrues a \$420 million loss. Table 3 shows that ROW decreases domestic sales by 23.53% and exports 4,049,000 MT to China due to the tariff.[10]

Because of the Chinese tariff, considerable reallocation of world trade occurs in the soybean market as the United States diverts its exports to the remaining importing regions: Mexico, the European Union, Japan, and Taiwan. Both the producer and consumer prices in Mexico, the

[7] Note that the ad valorem tariff, τ_{UC}, is zero in the baseline simulation, and U.S. exports to China, X_{UC}, are zero in the tariff scenario simulation, causing tariff revenues to be zero in both cases. For this reason, tariff revenue does not affect net surplus and is not included in Table 2.

[8] Zheng et al. (2018) found changes in U.S. net welfare of −\$1.8 billion.

[9] In 2016 and 2017, Brazil produced 114,100,000 MT and 117,000,000 MT, respectively, just behind U.S. production of 116,920,000 MT and 119,518,000 MT in the same years (U.S. Department of Agriculture, 2018b).

[10] ROW is comprised of some exporting and some importing regions, so as world price changes, this region could switch between exporting and importing.

European Union, and Taiwan decrease by 11.07%, 5.81%, and 11.93%, respectively. In Japan, producer price decreases by 2.78% and consumer price falls by 11.89% (recall that producer and consumer prices differ in Japan due to the production subsidy). As a consequence of these price changes, Mexican, EU, Japanese, and Taiwanese production decreases by 2.60%, 1.45%, 0.80%, and 1.78%, while consumption increases by 2.50%, 1.29%, 4.74%, and 3.55%, respectively. Each region's gain in consumer surplus exceeds its loss in producer surplus, and the net surplus gains in Mexico, the European Union, Japan, and Taiwan are $220 million, $350 million, $160 million, and $130 million, respectively.

Argentina is the third largest producer of soybeans, but is far behind the United States and Brazil, and thus plays only a modest role in the world soybean market. Paraguay is an exporter but a relatively small player in the soybean market. Both countries reallocate 100% of exports from ROW to China, causing Argentinian and Paraguayan prices to increase by 7.37% and 7.24%, respectively. As a result, Argentina sustains a 2.42% increase in production and 1.93% decrease in consumption, while Paraguay experiences a 2.40% increase in production and a 1.94% decrease in consumption. Because of the changes in prices, supply, and demand, Argentina gains $1.42 billion in producer surplus and loses $1.26 billion in consumer surplus. Paraguay gains only $250 million in producer surplus and loses $100 million in consumer surplus. Although producer and consumer surplus changes are much higher in Argentina than in Paraguay, the overall gain in welfare is nearly identical for the two exporters, with Argentina and Paraguay collecting $160 million and $150 million, respectively.

Canada, unlike other exporters, loses as a result of the Chinese tariff. The rationale for this result is that Canada traditionally exports to the European Union; but following the Chinese tariff on U.S. soybeans, the United States diverts exports to the European Union at a price with which Canadian exporters cannot compete. This causes Canada to lose its EU export market, thus increasing its availability to sell domestically and decreasing Canadian prices by 1.98%. These reduced prices cause Canadian production to decrease by 0.67% and its consumption to increase by 0.55%. Although this result is different from those of other exporters, it follows intuitively with the trade reallocation scenario given in the introduction. Estimations of this type of reallocation are possible only with the spatial equilibrium model. Ultimately, Canada endures a net surplus loss of $40 million, making it the only country besides the United States and China to suffer a net surplus loss as a consequence of the tariff.

We also aggregated the production, consumption, and surplus measures for the entire world, which are shown in the last row of Table 2. Total world production and consumption remain almost unchanged, increasing by only 0.006%, because the increased production of China and several of the exporting countries nearly proportionately matches the decrease in production of the other regions. Similarly, increased consumption in the United States, Canada, and several of the importing regions is roughly analogous to the decreased consumption of the remaining regions. Table 2 shows that both producer and consumer surplus decrease after the implementation of the Chinese tariff. Consequently, the world loses $1.75 billion in total welfare. This result is similar to the findings of Taheripour and Tyner (2018), who reported a total world welfare loss of $1.49 billion as a result of the Chinese tariff.

We also undertook analyses of 10%, 15%, and 20% tariff scenarios, which lead to world welfare losses of $0.94 billion, $1.04 billion, and $1.42 billion, respectively. These results clearly indicate the world's welfare inefficiencies escalate significantly as tariffs progressively increase and underscore the importance of moving toward freer trade rather than pursuing protectionist policies. This finding is congruent with economic trade theory in that larger tariffs create greater inefficiencies. The trade reallocations also vary considerably across different tariff scenarios. For example, under the 25% tariff rate scenario, the United States fully diverts its exports from China to other regions, and new trade between ROW and China emerges. However, under the 20% tariff rate, the United States diverts only 89.78% of its exports to China to other importers, and there is no emergence of trade between ROW and China. Additionally, under the 15% tariff rate, there is no emergence of trade between

Canada and China, and Canada loses only 2.10% (rather than 100%) of its exports to the European Union. Finally, under the 10% tariff rate, U.S. exports to China decline by only 73.80%, and the emergence of trade between Paraguay and China (which were experienced in the 25%, 20%, and 15% scenarios) no longer occurs.

Though the current study covers only the raw soybean market, further extensions of this study would benefit from including additional sectors, specifically oil and meal, which would help capture interlinkages among the primary commodity (soybeans) and final products (soy meal and soy oil). Including these sectors would allow the model to quantify changes such as China reducing imports of U.S. soybeans and augmenting the imports of soy meal and soy oil from other regions. Furthermore, it would allow the model to quantify price, production, and consumption in these additional sectors, and these results would be useful to producers and consumers in these allied sectors.

Conclusion

The trade war between the world's economic superpowers, the United States and China, will have drastic effects on the world economy. Though these effects span across hundreds of traded goods and impart spillover effects on many regions, we focus on soybeans because the United States and China have a particularly strong presence in the world soybean market. This tariff can be analyzed using several trade models such as nonspatial and gravity models, but the spatial equilibrium model is most ideally suited because it can quantify the tariff impacts on prices, production, consumption, and bilateral trade flows *simultaneously*. In doing so, this model captures the trade reallocations occurring in the world market.

We develop a theoretical model using general functional forms for supply and demand functions and demonstrate qualitative impacts of the tariff. The empirical analysis implements the theoretical model by applying the SEM to the world soybean market using the MCP approach. The baseline and tariff scenarios solve for the impacts of the Chinese tariff on the endogenous variables: prices, supply, demand, and trade flows. These quantitative solutions confirm the qualitative results of the theoretical analysis. Using the solved values of the endogenous variables, we compute welfare measures.

The results exhibit the widespread repercussions of the Chinese tariff on the world soybean market, including regions that are not directly involved in this trade war. The Chinese tariff on U.S. soybeans inflicts net losses on three countries: China, the United States, and Canada. China and the United States endure billions of dollars in losses, clearly illustrating the self-destructive economic consequences of protectionist policies. China loses because the higher prices resulting from the tariff harms consumers more than it helps producers. In contrast, U.S. losses are due to lower prices, which hurt producers more than they benefit consumers. Canada, on the other hand, incurs losses because the United States displaces some of Canadian exports to the European Union.

Brazil, the leading competitor to the United States in the world soybean market, is the largest beneficiary of this trade war as it captures much of the United States' lost market in China. Brazil has increased production and exports at an alarming rate in recent years, and this trade litigation could propel Brazil to surpass the United States as the world's largest soybean producer. Though Brazil and a few other regions might benefit from the Chinese tariff, the results show that the world as a whole incurs welfare loss, creating economic inefficiency.

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Appendix A

Empirical analysis of the 11 regions included in the model requires 11 market-clearing conditions and 11^2 spatial arbitrage conditions, for a total of 132 equations ($11 + 11^2 = 132$). As explained in the theoretical analysis section, we simplify the model to four regions consisting of two exporting regions—the United States (U) and Brazil (B)—and two importing regions—China (C) and the European Union (E). Therefore, we can reduce the 132 equations of the empirical analysis to 20 equations ($4 + 4^2 = 20$). Furthermore, because China does not export to the United States, Brazil, or the European Union; the European Union does not export to the United States, Brazil, or China; the United States does not export to Brazil; and Brazil does not export to the United States, 8 of the 16 spatial-arbitrage conditions can be removed. Ultimately, we are left with four market-clearing conditions and eight spatial-arbitrage conditions as shown below:

(A1) $$S_U(P_U^P) = D_U(P_U^C) + X_{UC} + X_{UE}$$

(A2) $$S_B(P_B^P) = D_B(P_B^C) + X_{BC} + X_{BE}$$

(A3) $$S_C(P_C^P) + X_{UC} + X_{BC} = D_C(P_C^C)$$

(A4) $$S_E(P_E^P) + X_{UE} + X_{BE} = D_E(P_E^C)$$

(A5) $$P_U^C = P_U^P - s_U + t_{UU}$$

(A6) $$P_C^C = P_U^P - s_U + t_{UC} + \tau_{UC}$$

(A7) $$P_E^C = P_U^P - s_U + t_{UE}$$

(A8) $$P_B^C = P_B^P + t_{BB}$$

(A9) $$P_C^C = P_B^P + t_{BC}$$

(A10) $$P_E^C = P_B^P + t_{BE}$$

(A11) $$P_C^C = P_C^P - s_C + t_{CC}$$

(A12) $$P_E^C = P_E^P + t_{EE}.$$

Substitution of equations (A5), (A8), (A11), (A12) into equations (A1), (A2), (A3), and (A4), respectively, results in the following eight equations:

(A13) $$S_U(P_U^P) = D_U(P_U^P - s_U + t_{UU}) + X_{UC} + X_{UE}$$

(A14) $$S_B(P_B^P) = D_B(P_B^P + t_{BB}) + X_{BC} + X_{BE}$$

(A15) $$S_C(P_C^C + s_C - t_{CC}) + X_{UC} + X_{BC} = D_C(P_C^C)$$

(A16) $$S_E(P_E^C - t_{EE}) + X_{UE} + X_{BE} = D_E(P_E^C)$$

(A17) $$P_C^C = P_U^P - s_U + t_{UC} + \tau_{UC}$$

(A18) $$P_C^C = P_B^P + t_{BC}$$

(A19) $$P_E^C = P_U^P - s_U + t_{UE}$$

(A20) $$P_E^C = P_B^P + t_{BE}.$$

Now, substituting equation (A17) into equation (A15) and equation (A19) into equation (A16) and equating equation (A17) with equation (A18) and equation (A19) with equation (A20) gives

$$\text{(A21)} \qquad S_U(P_U^P) = D_U(P_U^P - s_U + t_{UU}) + X_{UC} + X_{UE}$$

$$\text{(A22)} \qquad S_B(P_B^P) = D_B(P_B^P + t_{BB}) + X_{BC} + X_{BE}$$

$$\text{(A23)} \qquad S_C(P_U^P - s_U + t_{UC} + \tau_{UC} + s_C - t_{CC}) + X_{UC} + X_{BC} = D_C(P_U^P - s_U + t_{UC} + \tau_{UC})$$

$$\text{(A24)} \qquad S_E(P_U^P - s_U + t_{UE} - t_{EE}) + X_{UE} + X_{BE} = D_E(P_U^P - s_U + t_{UE})$$

$$\text{(A25)} \qquad P_U^P - s_U + t_{UC} + \tau_{UC} - t_{BC} = P_B^P$$

$$\text{(A26)} \qquad P_U^P - s_U + t_{UE} - t_{BE} = P_B^P.$$

Noting that equations (A25) and (A26) are equal due to arbitrage, substituting equation (A25) into equation (A22) yields the following four equations:[11]

$$\text{(A27)} \qquad S_U(P_U^P) = D_U(P_U^P - s_U + t_{UU}) + X_{UC} + X_{UE}$$

$$\text{(A28)} \qquad S_B(P_U^P - s_U + t_{UC} + \tau_{UC} - t_{BC}) = D_B(P_U^P - s_U + t_{UC} + \tau_{UC} - t_{BC} + t_{BB}) + X_{BC} + X_{BE}$$

$$\text{(A29)} \qquad S_C(P_U^P - s_U + t_{UC} + \tau_{UC} + s_C - t_{CC}) + X_{UC} + X_{BC} = D_C(P_U^P - s_U + t_{UC} + \tau_{UC})$$

$$\text{(A30)} \qquad S_E(P_U^P - s_U + t_{UE} - t_{EE}) + X_{UE} + X_{BE} = D_E(P_U^P - s_U + t_{UE}).$$

These are equations (4)–(7) in the text. Totally differentiating equations (A27)–(A30), treating transport costs as constant, and combining like terms yields

$$\text{(A31)} \qquad \left(\frac{\partial S_U}{\partial P_U^P} - \frac{\partial D_U}{\partial P_U^C}\right) dP_U^P - dX_{UC} - dX_{UE} = -\frac{\partial D_U}{\partial P_U^C} ds_U$$

$$\text{(A32)} \qquad \left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C}\right) dP_U^P - dX_{BC} = \left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C}\right) ds_U - \left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C}\right) d\tau_{UC}$$

$$\text{(A33)} \qquad \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C}\right) dP_U^P + dX_{UC} + dX_{BC} = \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C}\right) ds_U - \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C}\right) d\tau_{UC} - \frac{\partial S_C}{\partial P_C^P} ds_C$$

$$\text{(A34)} \qquad \left(\frac{\partial S_E}{\partial P_E^P} - \frac{\partial D_E}{\partial P_E^C}\right) dP_U^P + dX_{UE} = \left(\frac{\partial S_E}{\partial P_E^P} - \frac{\partial D_E}{\partial P_E^C}\right) ds_U,$$

which are then converted to the matrix form $\mathbf{Ax} = \mathbf{b}$ in the theoretical analysis section.

The steps involved in determining the tariff effects on Chinese demand are demonstrated in equations (A35)–(A38):

$$\text{(A35)} \qquad \frac{\partial D_C}{\partial \tau_{UC}} = \frac{\partial D_C}{\partial P_C^C}\left(\frac{\partial P_C^C}{\partial P_U^P}\frac{\partial P_U^P}{\partial \tau_{UC}} + \frac{\partial P_C^C}{\partial \tau_{UC}}\right)$$

$$\text{(A36)} \qquad = \frac{\partial D_C}{\partial P_C^C}\left(\frac{\left[\left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C}\right) + \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C}\right)\right]}{|\mathbf{A}|} + 1\right)$$

[11] Note that we were able to remove equation (A26) because it is equal to equation (A25).

$$\text{(A37)} \quad = \frac{\partial D_C}{\partial P_C^C} \left(\frac{\left[\left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C} \right) + \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C} \right) \right]}{|\mathbf{A}|} + \frac{|\mathbf{A}|}{|\mathbf{A}|} \right)$$

$$\text{(A38)} \quad = \frac{\partial D_C}{\partial P_C^C} \left(\frac{\left[\left(\frac{\partial S_U}{\partial P_U^P} - \frac{\partial D_U}{\partial P_U^C} \right) + \left(\frac{\partial S_E}{\partial P_E^P} - \frac{\partial D_E}{\partial P_E^C} \right) \right]}{\left[\left(\frac{\partial S_U}{\partial P_U^P} - \frac{\partial D_U}{\partial P_U^C} \right) + \left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C} \right) + \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C} \right) + \left(\frac{\partial S_E}{\partial P_E^P} - \frac{\partial D_E}{\partial P_E^C} \right) \right]} \right) < 0.$$

Similarly, the steps required in determining the tariff effects on Brazilian supply are

(A39)

$$\frac{\partial S_B}{\partial \tau_{UC}} = \frac{\partial S_B}{\partial P_B^P} \left(\frac{\partial P_B^P}{\partial P_U^P} \frac{\partial P_U^P}{\partial \tau_{UC}} + \frac{\partial P_B^P}{\partial \tau_{UC}} \right)$$

$$\text{(A40)} \quad = \frac{\partial S_B}{\partial P_B^P} \left(\frac{\left[\left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C} \right) + \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C} \right) \right]}{|\mathbf{A}|} + 1 \right)$$

$$\text{(A41)} \quad = \frac{\partial S_B}{\partial P_B^P} \left(\frac{\left[\left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C} \right) + \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C} \right) \right]}{|\mathbf{A}|} + \frac{|\mathbf{A}|}{|\mathbf{A}|} \right)$$

$$\text{(A42)} \quad = \frac{\partial S_B}{\partial P_B^P} \left(\frac{\left[\left(\frac{\partial S_U}{\partial P_U^P} - \frac{\partial D_U}{\partial P_U^C} \right) + \left(\frac{\partial S_E}{\partial P_E^P} - \frac{\partial D_E}{\partial P_E^C} \right) \right]}{\left[\left(\frac{\partial S_U}{\partial P_U^P} - \frac{\partial D_U}{\partial P_U^C} \right) + \left(\frac{\partial S_B}{\partial P_B^P} - \frac{\partial D_B}{\partial P_B^C} \right) + \left(\frac{\partial S_C}{\partial P_C^P} - \frac{\partial D_C}{\partial P_C^C} \right) + \left(\frac{\partial S_E}{\partial P_E^P} - \frac{\partial D_E}{\partial P_E^C} \right) \right]} \right) > 0.$$