Economic Impact of Competing Soy Investment Alternatives

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Abstract

Investments in different parts of the soybean value chain have varying impacts on farmer returns, but it is currently unknown which investments will deliver the most bang for the buck. These issues are complex because investments in one part of the soybean value chain have implications for other soybean chains. As well, many soybean producers grow corn in rotation. That means while corn and soybean producers compete for resources and market share, they also share numerous common interests and interactions. To address this issue an economic model was developed, encompassing the entire soybean value chain and its linkage with the corn market, farm to fork, to determine the economic impacts of different investment alternatives. The results suggest that focusing on supply-side investments yields the most substantial returns for farmers, especially when disregarding benefits for other consumers. Following farm-level investment, exports emerge as the second most profitable avenue for soybean producers. The effect of heightened demand for feed soybeans on soybean producers varies depending on the proportion allocated to livestock production, with the greatest surplus observed when directing investments toward poultry. In light of the connections to the corn market, the surge in demand for feed crops due to increased livestock production benefits corn producers more than soybean producers. While there's been a rise in consumer interest and demand for meat alternatives, investments in promoting these alternatives have minimal impact on soybean producer profits, as demand for edible soybean consumption remains limited. The findings contribute to providing valuable insights into investment strategies and policy development to bolster support for soybean producers by analyzing the impacts of investments in various segments of the soybean industry.

Introduction

The different parts of the soybean value chain benefit from financial investments through the Soybean Checkoff Program, which was established under the Soybean Promotion, Research, and Information Act of 1990 (SPRIA) (USDA AMS, 2023). The Soy Checkoff Program, operating as the United Soybean Board, has been instrumental in providing crucial support for research, marketing, and educational endeavors aimed at improving both the production and consumption of soybeans. Table 1 illustrates the contributions made by the US soybean checkoff program, including the number of projects for each specific objective in the 2018-2022 average. In contributed value, over 63% of the investments were directed toward enhancing soybean production, encompassing areas such as breeding and genetics, seed composition, and soybean disease management. The contributed value for food use was relatively small at 0.4%, and biodiesel and bioheat were similarly small at 0.3% (USB, 2018-2022).

Investments in different parts of the soybean value chain have divergent impacts on farmers' bottom lines, and yet it currently remains unknown which investments will produce the biggest bang for the buck. These issues are complicated by the fact that investments in one part of the soy value chain impact other soy chains. For example, efforts to increase demand for direct human consumption of soy protein (for example, in plant-based meat alternatives) are likely to spill over and affect prices of beef, pork, and chicken, and thus impact demand for soy meal. As a result, there is a need for economic research to determine the economic impacts of different investment alternatives.

These issues are particularly important to soybean producers at the moment as demand for soy-based biofuels is increasing alongside increases in demand for plant-based proteins. These relatively new issues are occurring alongside historical concerns related to trade, plant disease, and value-added soy (e.g., high-oleic). At present it is difficult to assess which of these factors should command the limited attention and funds of the United Soybean Board. Another issue is that soybean producers grow corn in rotation for the environment and crop productivity (Janovicek et al., 2021; Hall et al., 2019; Boyer et al., 2013), while simultaneously soybean and corn often contend as alternatives in the realms of feed grains (Hines and Briggs, 2021; Hoffman and Baker, 2011). That means while corn and soybean producers do compete for resources and market share, they also share numerous common interests and interactions. For this reason, the corn market, intertwined with the soybean market, should be considered when considering the profitability of soybean producers.

Table 1. Contributions by Checkoff, per Category (2018-2022 average)

Category	Contributed Value, $		Project	Category	Contributed Value, $		Project
Breeding & genetics	6,940,194	(23.0)	56	Climate change	211,131	(0.7)	1
Seed composition	4,763,034	(15.8)	16	Technology	186,161	(0.6)	4
Soybean diseases	3,484,688	(11.5)	41	Animal Nutrition	181,528	(0.6)	4
Insects and pests	2,175,060	(7.2)	26	Analytical standards & measurements	167,572	(0.6)	4
Crop management systems	1,655,336	(5.5)	33	Industrial use-Oil	165,888	(0.5)	3
Sustainability	1,654,032	(5.5)	6	Industrial use-Meal	158,495	(0.5)	1
Weed control	1,432,366	(4.7)	28	Soil and tillage management	151,534	(0.5)	5
Research Coordination	1,133,272	(3.8)	6	Cover Crops	151,005	(0.5)	4
Nematodes	1,081,940	(3.6)	15	Food use	107,873	(0.4)	3
Agronomy	834,499	(2.8)	27	Biodiesel/Bioheat	104,235	(0.3)	5
Aquaculture	658,600	(2.2)	6	New uses	101,477	(0.3)	3
Soil fertility	513,022	(1.7)	17	Soybean variety trials	83,326	(0.3)	3
Water quality & management	493,365	(1.6)	6	Irrigation	77,047	(0.3)	4
Environmental stress	458,656	(1.5)	7	Marketing	52,885	(0.2)	2
Communication	369,509	(1.2)	2	Economics	50,084	(0.2)	3
Education	308,014	(1.0)	7	Animal health	44,178	(0.1)	1
Soybean utilization	264,113	(0.9)	6	Weather	37,013	(0.1)	2
				Total	30,202,844	(100)	355

Note: The number in parentheses indicates the proportion of total contributions through checkoff by category.
Source: United Soybean Board, National Soybean Checkoff Research Database, 2018-2022. (https://soybeanresearchdata.com/)

This study entails the construction of an economic model of the soybean value chain – from farm to fork linked to the corn market. This is not a technical feasibility study of a particular innovation, but rather this study aims to determine market-wide impacts of different supply or demand shocks, some of which are brought about by innovation. Therefore, the objective of this study is to determine the economic impact of competing soy investment opportunities. Despite the varied nature of the specific impact of investment alternatives, each can be addressed through a unified economic model of the soybean value chain. The outcome is that alternative investment alternatives can be directly compared in an "apples to apples" framework. This study provides a rank-ordered list of outcomes in terms of the impacts on soybean prices and producer surplus. The findings of this study will help inform the United Soybean Board in the difficult task of setting future strategy and resource allocation.

Methods and Data

Figure 1 illustrates the soybean value chain linked to the corn market, demonstrating key features such as trade, livestock feed demand, biofuels, and food-grade use of soy oil and protein. An equilibrium displacement model is constructed, which models changes from an initial equilibrium that results from exogenous shocks to the markets in question (Alston, 1991; Wohlgenant, 2011). Endogenous variables (i.e., the variables that are determined in the model) include changes in farm-level soybean prices and production, changes in soybean exports, and changes in quantities of soy meal going toward different end uses. The model was used to determine the impact of investment alternatives by giving equivalent shocks of 10% to various sectors of supply and demand. Changes in prices and quantities can be used to determine changes in soy producer surplus. The model is a partial equilibrium model, which is simplified and focused on soybean and corn markets, ignoring other potential interactions across markets. We exclude other aspects of the soybean value chain that are relatively small such as soybean imports or not important to the study inquiry, and that can be excluded without changing the fundamental conclusions such as livestock imports and exports.

The visual representation of the value chain in Figure 1 can be converted to a mathematical representation of the sector. The equations developed for the equilibrium displacement model that portrays the U.S. soybean value chain are detailed in Appendix 1. The model consists of a total of 85 endogenous variables. The endogenous variables are solved with matrix algebra using an 85×85 matrix of model parameters and an 85×1 vector of exogenous shocks. Exogenous shocks consist of supply shifters or demand shifters. We estimate price and quantity changes according to investment alternatives by applying an exogenous shock of 10% to supply, processing, and retail demand at each stage of the soybean value chain. We also calculate how much of an exogenous shock would be needed for each part of processing and retail demand to achieve the same effect as a 10% exogenous shock to soybean supply.

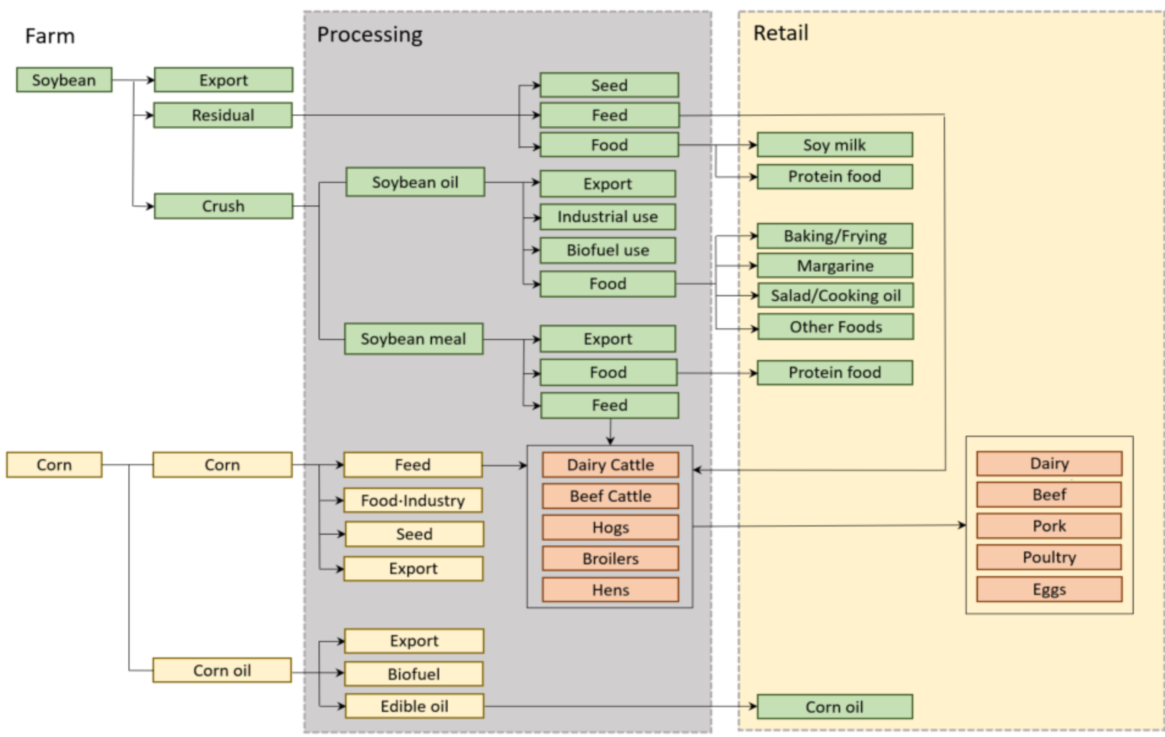

Figure 1. Soybean farm-to-retail value chain linked to the corn market

Equilibrium displacement models are typically specified using information on demand and supply elasticities as well as data on shares of production going to different uses before the shocks. Thus, values must be assigned to each parameter in equations to implement the model. The statistical values are from statistical data provided by the US governmental agencies and elasticity parameters are from previous literature. Table 2 to Table 4 shows soybean, soy oil, and soy meal use and quantity shares for various purposes used in the soybean model. Other assigned parameter values for the US soybean farm-to-retail value chain model are shown in Appendix 2. Most values are from related studies conducted before, but in the absence of available literature, assumed values for some parameters are used, which do not significantly affect the model estimation. For example, the quantity share of soybean residuals for seed, feed, and food use is assumed as 0.33, equivalently, because there is no previous literature or data for estimation. Given that soybean residuals constitute only 0.03% of the total supply, it is improbable that these values significantly influence the model estimation results.

Table 2. Soybean use and quantity shares for various usage (16/17 ~ 20/21 Average)

		Usage (Million *bu*)	Quantity Share				
Soybean		4,188	1.00				
	Crush	2,071	0.50				
	Export	1,999	0.50				
	Residuals	118	0.03	Seed	0.33[1]		
				Feed	0.33[1]	Dairy cattle	0.13
						Beef cattle	0.06
						Hog	0.20
						Poultry bird	0.46
						Hens	0.15
				Food	0.33[1]	Soymilk	0.50[1)]
						Plant-based protein	0.50[1)]

[1)] Author's assumption

Data: USDA ERS, Oil Crops Yearbook, Table 3 and Table 4 (16/17~20/21)

USDA NASS, Fats and Oils: Oilseed Crushing, Production, Consumption, and Stocks (16/17~20/21)

USB Market View database (16/17~20/21)

Table 3. Soy oil use and quantity shares for various usage (16/17 ~ 20/21 Average)

		Usage (MT)	Quantity Share		
Soy oil		11,010,002	1.00		
	Export	1,044,137	0.10		
	Industrial use	966,768	0.08		
	Biofuel	3,927,451	0.32		
	Food	6,115,783	0.50	Cooking oil	0.65
				Baking oil	0.32
				Margarine	0.02
				Other	0.01

Data: USDA ERS, Oil Crops Yearbook, Table 5, and USB Market View database (16/17~20/21)
USB Market View database (16/17~20/21)

Table 4. Soy meal use and quantity shares for various usage (16/17 ~ 20/21 Average)

		Usage (1,000 short tons)	Quantity Share	
Soy meal		49,470	1.00	
	Export	13,316	0.27	
	Food	495	0.01	
	Feed	35,659	Dairy cattle	0.09
			Beef cattle	0.04
			Hog	0.14
			Poultry bird	0.33
			Hens	0.11

Data: USDA ERS, Oil Crops Yearbook, Table 4 (16/17~20/21)
USDA NASS, Fats and Oils: Oilseed Crushing, Production, Consumption, and Stocks (16/17~20/21)
USB Market View database (16/17~20/21)

Results

A partial equilibrium system of equations linking the farm supply of soybeans and corn to the retail consumption of food products produced with soybean oil, meal, corn, and corn oil is constructed to estimate the economic impacts of different investment alternatives for the US soybean market. To determine the economic impacts of different investment alternatives, we introduced one supply-side shock and seven demand-side shocks. Supply shock is defined 10% decrease in the marginal cost of producing soybean. Demand shocks are defined as a 10% increase in demand across various sectors, including exports, the utilization of soybeans for biofuel production, industrial processing, animal feed usage, and the retail demand for soy-based food and meat products. Furthermore, when it comes to animal-derived foods, they are categorized into cattle, port, dairy, poultry, and eggs, while soy-based food items encompass products like soy milk, edible soy oil, and plant-based protein products using soybean. Therefore, we assess the soybean producer surplus of sector-specific investment alternatives by examining how equilibrium price and quantity change across all scenarios. These changes are determined by applying an identical 10% shock to all supply and demand sectors separately for comparison, assuming no other supply or demand shocks to the soybean value chain.

Impact of increase in supply

Table 5 shows the estimated impacts of shock caused by investment at the farm level. At the farm level, the shift in the supply curve for soybeans increases the quantity of soybeans produced at 2.005% and declines the farm-level price of soybeans at 2.289%. As demand for feed grains put into animal products increases caused by falling soybean prices, corn production rises by 0.014%, and the farm-level price of corn rises by 0.05%. As a result, the soybean producers' surplus increased by $ 3,635 million. Considering the corn producer's surplus increases by $35 million, a total of $3,670 million considering both soybean and corn producers' surplus changes.

Table 5. Estimated impacts of exogenous shocks on the soybean supply

	Production (% change)		Price (% change)		Surplus effect ($ million)		
10% Shock	Soy	Corn	Soy	Corn	Soy	Corn	Soy + Corn
Supply shock							
Soybean	2.005	0.014	-2.289	0.050	3,635	35	3,670

Table 6 shows the estimated impacts of demand shock caused by different investment alternatives in the soybean market.

Table 6. Estimated impacts of exogenous shocks in the soybean industry

10% Shock		Production (% change)		Price (% change)		Surplus effect ($ million)		
		Soy	Corn	Soy	Corn	Soy	Corn	Soy + Corn
Demand shock								
Export	Soybean	1.579	-0.038	6.073	-0.132	2,857	-92	2,765
	Soybean meal	0.187	-0.063	0.718	-0.217	335	-151	185
	Soybean oil	0.039	0.007	0.150	0.025	70	17	88
Soybean biofuel		0.013	0.002	0.051	0.009	24	6	30
Industrial use		0.013	0.002	0.048	0.008	23	6	28
Feed use	Soy-cattle	0.004	-0.001	0.014	-0.004	7	-3	4
	Soy-hog	0.013	-0.004	0.050	-0.014	23	-10	13
	Soy-dairy	0.008	-0.003	0.032	-0.009	15	-6	9
	Soy-poultry	0.030	-0.010	0.117	-0.033	55	-23	31
	Soy-hens	0.010	-0.003	0.039	-0.011	18	-8	10
Livestock	Cattle	0.006	0.181	0.024	0.625	11	435	447
	Hog	0.021	0.196	0.081	0.675	38	470	507
	Dairy	0.042	0.200	0.163	0.691	76	481	557
	Poultry	0.056	0.146	0.214	0.502	100	350	449
	Hens	0.009	0.025	0.036	0.085	17	59	76
Retail meat	Beef	0.007	0.201	0.027	0.693	13	482	495
	Pork	0.061	0.567	0.234	1.956	109	1,364	1,473
	Dairy	0.029	0.136	0.110	0.469	51	326	378
	Poultry	0.043	0.113	0.166	0.391	78	272	349
	Eggs	0.014	0.038	0.055	0.130	26	91	116
Retail soy food	Plant-protein	0.019	-0.002	0.073	-0.008	34	-5	29
	Soymilk	0.003	-0.000	0.011	-0.000	5	-0	5
	Cooking oil	0.085	0.016	0.328	0.055	153	38	191
	Baking oil	0.042	0.008	0.162	0.027	75	19	94
	Margarine	0.003	0.000	0.010	0.002	5	1	6
	Other	0.001	0.000	0.005	0.001	2	1	3

Impact of increase in foreign demand

The results of demand shocks for the soybean export sector show how US soybean farmer profitability is affected by changes in foreign demand. Soybean exports consist of three types of products: soybean raw material, crushed soybean meal, and soybean oil. When foreign demand increases by 10% for soybeans and soybean meal, soybean production rises, resulting in price increases. Increased exports of soybeans and soybean meal reduce the soybean demand for animal feed, which will lead to a decrease in livestock production, consequently affecting the corn market, which is closely linked to feed grain consumption. There is a decrease in corn production, along with lower corn prices according to soybean and soybean meal export shock. Consequently, soybean producers' surpluses increase by $2,857 million and $335 million caused by soybean and soybean meal export shock, respectively, when the soybean market and corn market are considered together, at $2,765 million and $185 million.

When the foreign demand for soybean oil rises by 10%, there is a corresponding increase in the supply of soybean meal for livestock feed. This is because the production of soybean meal increases which is a by-product, along with the production of soybean oil. With greater input of soybean meal in livestock feed, there is an uptick in livestock production. Consequently, corn demand for feed also increases, and prices rise. The resulting surplus growth for soybean producers is $70 million, and the sum of surplus growth for soybean and corn producers is $88 million.

Impact of increase in soybean demand for biofuel and industrial use

The economic impact of increased demand for soybean oil used in biofuel production on U.S. soybean producers is estimated to be a change in producer surplus of $24 million. Similarly, the increase in demand for industrial use of soybean oil resulted in the change in soybean producer surplus is estimated to be $23 million.

Impact of increase in soybean demand for animal feed and livestock supply

About 72% of soybean meal and about 38% of produced corn is used for animal feeding. The increase in feed demand of soybeans or the increase in feed demand, including soybean and corn, due to the increase in livestock supply affects the soybean and corn market. The magnitude of the impact depends on the proportion of the specific feed grains consumed by livestock. In feed demand of soybeans, poultry production accounts for the largest at 33%, and beef cattle production accounts for the smallest at 4%. Increased feed demand for soybeans raises soybean production and prices but leads to lower demand and prices of corn that can substitute soybeans. Therefore, the soybean producer surplus for the 10% increase in feed demand for soybeans is estimated to be between $7 and $55 million, depending on the type of livestock products. Soybean and corn combined producer surplus is estimated to be between $4 and $31 million, which is less than considering only the soybean market.

The increase in the supply of livestock results in an increase in feed demand, both soybeans and corn, in proportion to the feed grain used in livestock production. Thus, a 10% increase in livestock supply raises production and prices of both soybeans and corn. When considering the soybean market alone, soybean producer surplus is estimated at $11 to $100 million, and when considering both soybean and corn markets, the sum of soybean and corn producer surplus at $76 to $557 million is estimated.

Impact of increase in retail meat demand

The increase in meat demand at the retail stage appears to have a greater impact on soybean and corn markets than the increase in feed grain demand in the processing stage. A 10% increase in meat demand at the retail market raises both the production and price of soybeans and corn, as does an increase in feed grain demand for livestock. As a result, soybean producer surplus from investments to promote meat demand is estimated at $13-109 million in the soybean market and $116-1,473 million in both the soybean and corn markets depending on the meat product variety.

Impact of increase in demand for retail soy food

The results of demand shocks for retail soybean food consumption show the economic impact of growth in plant-based protein demand on U.S. soybean prices, production, and profitability. Moreover, the relative impact of investments to increase human-edible soy in the form of protein compared to edible soy oil can be explained. As shown in Table 6, investing to stimulate retail demand for edible soybean oil is more effective in terms of soybean producer surplus than increasing demand for plant-protein products and soymilk. This is believed to be because the proportion of soybeans used to produce soybean foods is less than 1% of total production. A 10% increase in edible soybean cooking oil demand is estimated to increase soybean producer surplus by $153 million, and a 10% increase in demand for soybean-based protein products is estimated to increase soybean producer surplus by $34 million. A 10% increase in soymilk demand is projected to increase soybean producer surplus by $5 million, which is the smallest impact resulting from a demand shock for retail soymilk food.

Comparison of producer surplus by investment alternatives

Figure 2 shows the change in soybean and corn producer surplus by different investment alternatives. Investing to reduce marginal costs at the farm-level represents the most lucrative approach for soybean producers. Thus, farm-level investment prioritizes producer surplus without considering consumer interests or total social welfare. Given that demand shocks don't directly affect the producer but instead have a consequential effect on the producer by affecting the market, it's reasonable that the influence on the producer will be less pronounced compared to supply shocks. The positive shocks in the foreign demand, which account for about 48% of total soybean production, generate the second-largest producer surplus after the supply shock. Considering the corn market, which is linked to the soybean market in the demand for feed grains, the increase in the demand for feed soybeans has an adverse impact on the corn market. However, the increase in livestock feed demand and the demand for retail meat also lead to increased corn producer surplus. Notably, encouraging meat demand in the retail market is more advantageous to corn producers than to soybean producers.

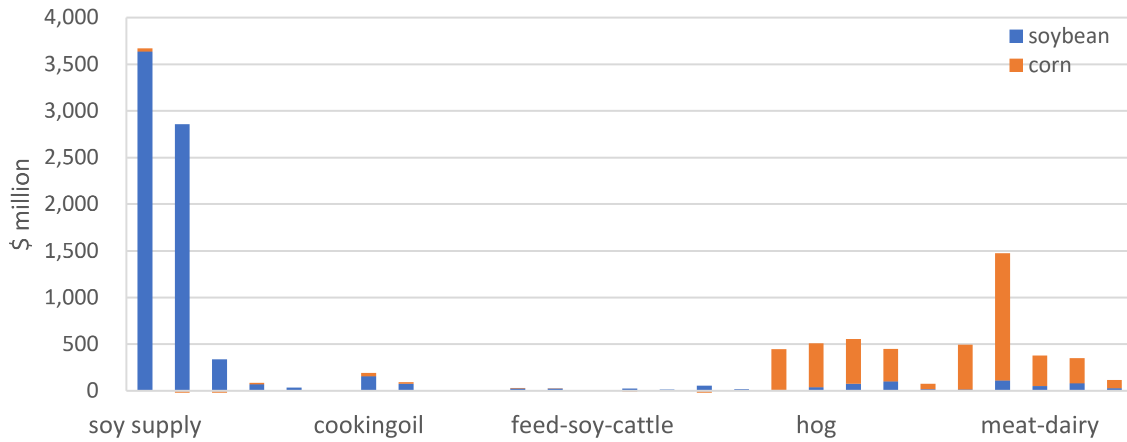

Figure 2. Change in soybean and corn producer surplus by each exogenous shock

The magnitude of investment alternatives to generate equivalent effects

We estimate the demand shocks required to achieve effects equivalent to a 10% soybean supply shock (Table 7 and Figure 3). In all demand sectors except soybean exports, the magnitude of the shock needed to generate an equivalent impact on direct investment in producers exceeds 100%. When funds are directly invested in producers to shift the supply curve, most of the resulting profit goes to producers. However, when investments are directly towards the demand side, a significant portion of the profits is passed on to consumers. As a result, both investment strategies, whether in supply or demand, contribute to enhancing social welfare, Nevertheless, investing in supply tends to favor producers, while investing in demand benefits consumers more.

Given the change in soybean producer surplus due to a 10% supply shift, we estimate the equivalent shock in the export sector to be 13% for soybean export, 107% for soybean meal export, and 514% for soybean oil export. The demand sectors that require the largest shock to achieve the same effect as the supply shock (10%) are the demand for edible oil for the “other” category (15,277%) and the demand for edible oil for margarine (7,638%), and soy milk (7,207%). Their equivalent shock estimates are so large because the proportion of soybeans consumed for these uses is smaller than that of other demands.

Table 7. Demand shocks with equivalent effects to 10% soybean supply shock

Surplus of producers		Equivalent shock (Soy)	Equivalent shock (Soy + Corn)
Equivalent surplus effect ($ million)		3,635	3,670
Supply shock (% change)			
Soybean		10	10
Demand shock (% change)			
Export	Soybean	13	13
	Soybean meal	107	192
	Soybean oil	514	417
Soybean biofuel		1,501	1,216
Industrial use		1,595	1,293
Feed use	Soy-cattle	5,425	9,301
	Soy-hog	1,550	2,657
	Soy-dairy	2,411	4,134
	Soy-poultry	658	1,127
	Soy-hens	1,973	3,382
	Livestock		
	Cattle	3,151	82
	Hog	955	72
	Dairy	475	66
	Poultry	361	81
	Hens	2,123	478
	Retail meat		
	Beef	2,843	74
	Pork	330	25
	Dairy	699	97
	Poultry	464	105
	Eggs	1,393	314
Retail soy food	Plant-protein	1,061	1,268
	Soymilk	7,207	7,514
	Cooking oil	235	190
	Baking oil	477	387
	Margarine	7,638	6,189
	Other	15,277	12,379

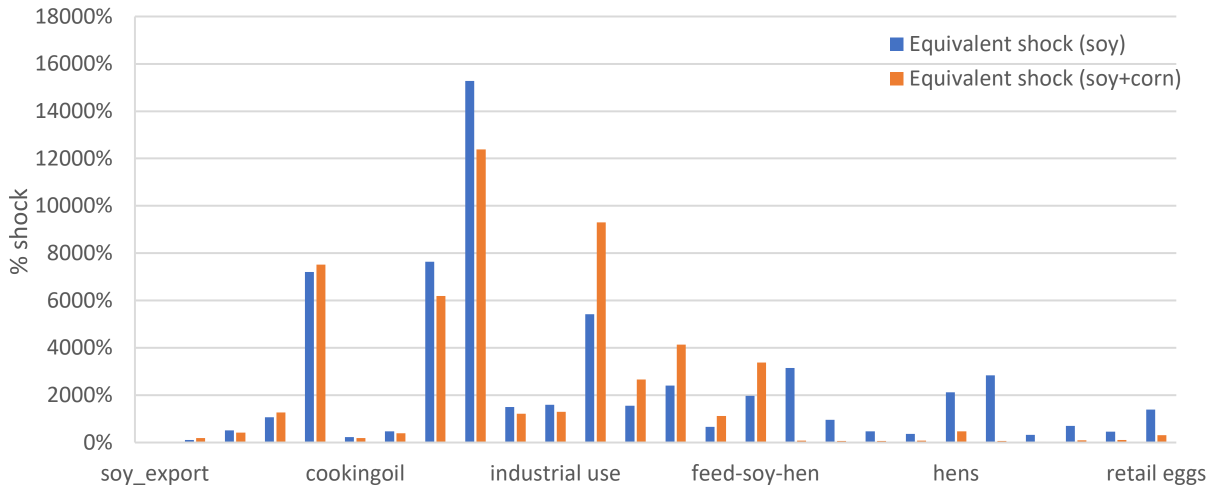

Figure 3. Demand shocks with equivalent effects to 10% soybean supply shock

The equivalent shocks for cooking (235%) and baking oils (477%) are relatively modest compared to other retail demand sectors. This implies that although it does not generate as much effect as it is directly invested in producers, the resources that are invested in these demands can benefit producers. As for feed grain demand, it appears that the effect of promoting meat demand in the retail market is greater than the investment effect on feed soybean demand itself. According to Tonsor and Bina (2023), plant-based proteins have a weak substitution with meat products, and because the market for plant protein is still small, it takes a relatively large shock (1,061%) to produce an effect equivalent to direct investment in producers (10%).

Conclusion

This study aims to determine the impacts of investment alternatives in different parts of the soybean value chain on soybean producer surplus. The problem is compounded by the fact that investments made in one segment of the soybean value chain have repercussions on other interconnected segments of the soy industry. To address this issue an economic model was developed, encompassing the entire soybean value chain and its linkage with the corn market, farm to fork. The findings indicate that the investment in the supply side generates the largest impact on the farmers' returns when we do not consider other consumers' benefits. Investment in exports is the second largest profitable for soybean producers following farm-level investment. The impact of increased demand for feed soybeans on soybean producers depends on the proportion of input for livestock production, with the largest producer surplus when invested in poultry. Considering the links to the corn market, increased demand for feed crops due to increased livestock supply is more favorable to the corn market than to soybeans. Recently, consumer interest and demand for meat alternatives have been increasing, but the impact of promotion investments on soybean producer profits is not significant, as demand for edible consumption of soybeans is still quite limited, less than 1% of total production.

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Appendix 1. Mathematical equations for the equilibrium displacement model

The following characterizes the equilibrium displacement economic model, starting with the farm supply of soybeans (the left-hand side of Figure 1) and working toward final retail demand (the right-hand side of Figure 1).

Farm

The farm-level supply of soybeans is given by:

1) $\hat{x}_{soy} = \varepsilon_{soy}(\widehat{w}_{soy} + k)$

where $\hat{x}_{soy}$ is the proportionate change in soybean supplied by U.S. farmers, $\widehat{w}_{soy}$ is the proportionate change in farm-level soybean price, ε_{soy} is the own-price elasticity of supply for soybeans, and k is an exogenous supply shifter that can be interpreted as a change in marginal cost.

The farm supply of soybeans is allocated to three possible uses such as export, crush, and residual, as shown in the equation below:

2) $\hat{x}_{soy} = \sum_{j=1}^{3} SS_{soy,j} \cdot \hat{x}_{soy,j}$ for $j = export, resid, crush$

where $\hat{x}_{soy,j}$ is the proportionate change in the quantity of soybeans allocated to the j^{th} market, and where $SS_{soy,j}$ is the quantity share of soybeans going to the j^{th} market.

Demands for U.S. soybeans by foreign buyers is given by:

3) $\hat{x}_{soy,export} = \eta_{soy,export} \cdot (\widehat{w}_{soy} + \delta_{soy,export})$

where $\eta_{soy,export}$ is the own-price elasticity of demand for soybeans by foreign markets and $\delta_{soy,export}$ is an exogenous shock to export demand.

Soybean residuals are usually allocated to seed, feed, and food as shown in the equation below:

4) $\hat{x}_{soy,resid} = \sum_{j=1}^{3} SL_{resid,j} \cdot \hat{x}_{resid,j}$ for $j = seed, feed, food$

where $\hat{x}_{resid,j}$ is the proportionate change in the quantity of soybeans allocated to the j^{th} market, and where $SL_{resid,j}$ is the quantity share of soybean residuals going to the j^{th} market.

Demands for soybean residual by seed users are given by:

5) $\hat{x}_{resid,seed} = \eta_{resid,seed} \cdot \widehat{w}_{soy}$

where $\eta_{resid,seed}$ is the own price elasticity of demand for soybean residuals by seed users.

Demands for soybean residuals for protein food processing are given by:

6) $\hat{x}_{resid,food} = \sum_{j=1}^{2} SF_{resid-food,j} \cdot \hat{x}_{resid-food,j}$ for $j = soymilk, plant\ protein$

where $SF_{resid-food,j}$ is the quantity share of soybean residuals for food production allocated to the soymilk and plant-based meat alternatives market.

The constrained derived demand, assuming perfectly elastic supplies of other inputs, for soybean residuals by each foodstuff is:

7-8) $\hat{x}_{resid-food,j} = \eta_{resid,j} \cdot \widehat{w}_{soy} + \hat{Q}_j$ for $j = soymilk, plant\ protein$

where $\eta_{resid,j}$ is the own price elasticity of demand for soybean residuals by soymilk and plant-based meat alternatives processors and $\hat{Q}_j$ is the proportionate change in the retail quantity of each food product.

The proportionate change in the retail price of soymilk and the final demands for soymilk are:

9) $\hat{P}_{soymilk} = \widehat{w}_{soy}$

10) $\hat{Q}_{soymilk} = \sum_{k=1}^{2} \eta_{soymilk,k} \cdot (\hat{P}_k + \delta_k)$ for j, $k = soymilk, dairy$

where $\hat{Q}_j$ is the proportionate change in the retail quantity of soymilk and dairy milk products, and $\eta_{soymilk,k}$ is the elasticity of demand for retail soymilk products caused by a 1% change in the price of k

product and δ_k is demand shift for k product.
The supplies of soybean residuals are used for animal feedings such as dairy cattle, beef cattle, hogs, poultry, and egg-laying hens, which is given by:

11) $\hat{x}_{resid,feed} = \sum_{j=1}^{5} SA_{resid-feed,j} \cdot \hat{x}_{resid-feed,j}$ for $j = dairy\_cattle, beef\_cattle, hog, bird, hen$

where $SA_{resid-feed,j}$ is the quantity share of soybean residuals going to the jth market.
Output-constrained derived demands for soybean residuals by dairy cattle, beef cattle, hogs, poultry, and egg-laying hens are, associated with the corn market as a substitute for soybean used as animal feeds:

12-16) $\hat{x}_{resid-feed,j} = \hat{x}_j + \sigma_a \cdot \left(\hat{w}_j - (\hat{w}_{soy} + \delta_{soy,feed})\right)$ for $j = dairy\_cattle, beef\_cattle, hog, bird, hen$

where σ_a is the elasticity of substitution between soybean and corn for animal feeding, and $\hat{w}_j$ is the proportionate change in the price of j product. $\delta_{soy,feed}$ are exogenous soybean demand shifts for feed consumption by cattle, hogs, poultry, and egg-laying hens.

Processing

The soybeans produced, excluding exports and residuals, are crushed and converted into soybean meal and soybean oil. The derived demand for soybeans by the crushing sector is

17) $\hat{x}_{soy,crush} = \sum_{j=1}^{3} \eta_{soy-crush,j} \cdot \hat{w}_j$ for $j = soy, oil, meal$

where $\eta_{soy-crush,j}$ is the derived demand elasticity for soybean crushed with respect to a change in the price of input/output j.
The output supplies of oil and meal from the soybean crushed are given:

18) $\hat{x}_{oil} = \sum_{j=1}^{3} \varepsilon_{oil,j} \cdot \hat{w}_j$ for $j = soy, oil, meal$

19) $\hat{x}_{meal} = \sum_{j=1}^{3} \varepsilon_{meal,j} \cdot \hat{w}_j$ for $j = soy, oil, meal$

where $\varepsilon_{oil,j}$ and $\varepsilon_{meal,j}$ are supply elasticity for soybean oil and meal, respectively.

Soybean oil

The supply of soybean oil is allocated to one of four different markets such as exports, industrial uses, food, or biofuels, as shown in the equation below:

20) $\hat{x}_{oil} = \sum_{j=1}^{4} SO_{oil,j} \cdot \hat{x}_{oil,j}$ for $j = export, industry, biofuel, food$

where $SO_{oil,j}$ is the quantity share of soybean oil going to the j^{th} market.
Demands for soybean oil by foreign buyers, industrial uses, and biofuel are given by:

21) $\hat{x}_{oil,export} = \eta_{oil,export} \cdot (\hat{w}_{oil} + \delta_{oil,export})$

22) $\hat{x}_{oil,industrial} = \eta_{oil,industrial} \cdot (\hat{w}_{oil} + \delta_{oil,industrial})$

23) $\hat{x}_{oil,biofuel} = \eta_{oil,biofuel} \cdot (\hat{w}_{oil} + \delta_{oil,biofuel})$

where $\eta_{oil,export}$, $\eta_{oil,industrial}$, and $\hat{x}_{oil,biofuel}$ are the own price elasticity for export demand, industrial use, and biofuel use of soybean oil. $\delta_{oil,export}$, $\delta_{oil,industrial}$, and $\delta_{oil,biofuel}$ are exogenous demand shifts by foreign buyers, industrial users, and biofuel producers.
According to the United Soybean Board data, soybean oil is used for food divided into four foodstuffs such as baking/frying, margarine, salad dressing/cooking oil, or other foods using soybean oil.

24) $\hat{x}_{oil,\text{food}} = \sum_{j=1}^{4} SF_{oil,j} \cdot \hat{x}_{oil-food,j}$ for $j = baking, margarine, cooking\ oil, other$

where $SF_{oil,j}$ is the quantity share of food-grade soybean oil going to each foodstuff market.
The constrained derived demand, assuming perfectly elastic supplies of other inputs, for food grade oil by each foodstuff is:

25-28) $\hat{x}_{oil-food,j} = \eta_{oil,j} \cdot \hat{w}_{oil} + \hat{Q}_j$ for $j = baking, margarine, cooking\ oil, other$

where $\hat{Q}_j$ is the proportionate change in the retail quantity of food product j.

Output supplies, assuming constant returns to scale, for the four oil-based food products are:

29-32) $\hat{P}_j = SR_{oil,j} \cdot \hat{w}_{oil}$ for $j = baking, margarine, cookin\ oil, other$

where $\hat{P}_j$ is the proportionate change in the retail price of oil-based food product j, and $SR_{oil,j}$ is the share of the total cost to produce food j that is attributed by the cost of soybean oil.

The final demands for oil-derived foodstuffs are:

33-37) $\hat{Q}_j = \sum_{k=1}^{5} \eta_{j,k} \cdot \left(\hat{P}_k + \delta_k\right)$ for $j = baking, margarine, cooking\ oil, other, corn\ oil$

$k = baking, margarine, cooking\ oil, other, corn\ oil$

where $\eta_{j,k}$ is the elasticity of demand for retail product j caused by a 1% change in the price of k product and δ_k is demand shift indicating the proportionate change in consumer willingness-to-pay for k product.

Soybean meal

The supply of soybean meal is allocated to export, protein food, and animal feeding, which is given by:

38) $\hat{x}_{meal} = \sum_{j=1}^{3} SM_{meal,j} \cdot \hat{x}_{meal,j}$ for $j = export, food, feed$

where $SM_{meal,j}$ is the quantity share of soybean meal going to the j^{th} market.

Demand for soybean meal by foreign buyers is:

39) $\hat{x}_{meal,export} = \eta_{meal,export} \cdot (\hat{w}_{meal} + \delta_{meal,export})$

Soybean meals is used by edible protein product processors as shown below:

The constrained derived demand, assuming perfectly elastic supplies of other inputs, for soybean meal by edible protein product processors is:

40) $\hat{x}_{meal,food} = \eta_{meal,food} \cdot \hat{w}_{meal} + \hat{Q}_{plant\ protein}$

where $\eta_{meal,food}$ is the own price elasticity of demand for soybean meal by meat alternatives food processors and $\hat{Q}_{protein}$ is the proportionate change in the retail quantity of protein food products. The proportionate change in the retail price of plant-based protein food is:

41) $\hat{P}_{protein\ food} = \sum_{k=1}^{2} SR_k \cdot \hat{w}_k$ for $k = soy, meal$

where $SR_{k,j}$ is the input k's share of the total cost to produce retail good j.

The supplies of soybean meal are used for animal feedings such as dairy cattle, beef cattle, hogs, poultry, and egg-laying hens, which is given by:

42) $\hat{x}_{meal,feed} = \sum_{j=1}^{5} SA_{meal-feed,j} \cdot \hat{x}_{meal-feed,j}$ for $j = dairy\_cattle, beef\_cattle, hog, bird, hen$

where $SA_{meal-feed,j}$ is the quantity share of soybean meal going to the j^{th} market.

Output-constrained derived demands for soy meal by dairy cattle, beef cattle, hogs, poultry, and egg-laying hens are, associated with the corn market as a substitute for soybean meal used as animal feeds:

43-47) $\hat{x}_{meal-feed,j} = \hat{x}_j + \sigma_a \cdot \left(\hat{w}_j - (\hat{w}_{meal} + \delta_{meal,feed})\right)$ for $j = dairy\_cattle, beef\_cattle, hog, bird, hen$

where σ_a is the elasticity of substitution between soybean and corn for animal feeding, and $\hat{w}_j$ is the proportionate change in the price of j product. $\delta_{meal,feed}$ are exogenous soybean meal demand shifts for feed consumption by cattle, hogs, poultry, and egg-laying hens.

Output supplies of dairy cattle, beef cattle, hogs, poultry, and egg-laying hens are:

48-52) $\hat{w}_j = \sum_{k=1}^{3} SR_{k,j} \cdot \hat{w}_k$ for $k = soy, meal, corn, j = dairy\_cattle, beef\_cattle, hog, bird, hen$

where $SR_{k,j}$ is the cost share of producing j animal product attributable to soybean or corn output.

The changes in derived demands for dairy cattle, beef cattle, hogs, poultry, and egg-laying hens are:

53) $\hat{x}_{dairy\_cattle} = \eta_{daity\_cattle} \cdot (\widehat{w}_{dairy\_cattle} + \delta_{dairy\_cattle}) + \hat{Q}_{dairy}$
54) $\hat{x}_{beef\_cattle} = \eta_{beef\_cattle} \cdot (\widehat{w}_{beef\_cattle} + \delta_{beef\_cattle}) + \hat{Q}_{beef}$
55) $\hat{x}_{hog} = \eta_{hog} \cdot (\widehat{w}_{hogs} + \delta_{hog}) + \hat{Q}_{pork}$
56) $\hat{x}_{bird} = \eta_{bird} \cdot (\widehat{w}_{bird} + \delta_{bird}) + \hat{Q}_{poultry}$
57) $\hat{x}_{hen} = \eta_{hen} \cdot (\widehat{w}_{hen} + \delta_{hen}) + \hat{Q}_{eggs}$
Output supplies of dairy, beef, pork, poultry, and eggs are:
58) $\hat{P}_{dairy} = SR_{dairy\_cattle,dairy} \cdot \widehat{w}_{dairy\_cattle}$
59) $\hat{P}_{beef} = SR_{beef\_cattle,beef} \cdot \widehat{w}_{beef\_cattle}$
60) $\hat{P}_{pork} = SR_{hog,pork} \cdot \widehat{w}_{hog}$
61) $\hat{P}_{poultry} = SR_{bird,poultry} \cdot \widehat{w}_{bird}$
62) $\hat{P}_{eggs} = SR_{hens,eggs} \cdot \widehat{w}_{hen}$
where $SR_{j,k}$ is the share of the total cost of producing retail food *k* which is explained by the cost of input *j*.
Final retail demands for animal-derived foodstuffs are given by:
63-67) $\hat{Q}_j = \sum_{k=1}^{5} \eta_{j,k} \left(\hat{P}_k + \delta_k\right)$ for $j = beef, pork, poultry, eggs, plant\ protein$
$k = beef, pork, poultry, eggs, plant\ protein$
68) $\hat{Q}_{dairy} = \sum_{k=1}^{2} \eta_{dairy,k} \left(\hat{P}_k + \delta_k\right)$ for $k = dairy, soymilk$
where $\eta_{j,k}$ is the elasticity of demand for retail product *j* caused by a 1% change in the price of product *k* and δ_k is demand shift indicating the proportionate change in consumer willingness-to-pay for *j* product.
Related corn market
Soybeans and corn processed into feed are consumed as input for livestock production, while soybean oil and corn oil are utilized by consumers in food products. They can potentially substitute for each other, and the soybean and corn markets are interconnected because changes in supply and demand for one crop can affect the other. Therefore, we need equations for the corn market to establish a connection with the soybean value chain. Equations for the corn market as a substitute for soybeans are:
69) $\hat{x}_{corn} = \varepsilon_{corn} \cdot \widehat{w}_{corn}$
70) $\hat{x}_{corn} = \sum_{j=1}^{4} CS_{corn,j} \cdot \hat{x}_{corn,j}$ for $j = feed, food, seed, export$
71-73) $\hat{x}_{corn,j} = \eta_{corn,j} \cdot \widehat{w}_{corn}$ for $j = food, seed, export$
74) $\hat{x}_{corn,feed} = \sum_{j=1}^{5} CA_{corn,j} \cdot \hat{x}_{corn,j}$ for $j = dairy\_cattle, beef\_cattle, hogs, bird, hen$
75-79) $\hat{x}_{corn,j} = \hat{x}_j + \sigma_a \cdot \left(\widehat{w}_j - \widehat{w}_{corn}\right)$ for $j = dairy\_cattle, beef\_cattle, hog, bird, hen$
80) $\hat{x}_{corn\ oil} = \varepsilon_{corn\ oil} \cdot \widehat{w}_{corn\ oil}$
81) $\hat{x}_{corn\ oil} = \sum_{j=1}^{3} CO_{corn\ oil,j} \cdot \hat{x}_{corn\ oil,j}$ for $j = export, biofuel, edible\ oil$
82-83) $\hat{x}_{corn\ oil,j} = \eta_{corn\ oil,j} \cdot \widehat{w}_{corn\ oil}$ for $j = export, biofuel$
84) $\hat{x}_{corn\ oil,edible\ oil} = \eta_{corn\ oil,corn\ oil} \cdot \widehat{w}_{corn\ oil} + \hat{Q}_{corn\ oil}$
85) $\hat{P}_{corn\ oil} = \widehat{w}_{corn\ oil}$
The model consists of a total of 85 endogenous variables such as proportionate changes in farm- and wholesale-level quantities, $\hat{x}_j$, and prices, $\widehat{w}_j$, retail-level quantities, $\hat{Q}_j$, and prices $\hat{P}_j$. Exogenous shocks consist of supply shifters, *k*, or demand shifters δ. The endogenous variables can be solved with matrix algebra using a 85×85 matrix of model parameters and a 85×1 vector of exogenous shocks.

Appendix 2. Model parameterization

Equilibrium displacement models are typically specified using information on demand and supply elasticities as well as data on shares of production going to different uses. Table A2-1 ~ A2-5 shows the cost-share of farm-retail products for different products used in the model. Table A2-6 ~ A2-12 shows the elasticity values assigned to model parameters and the sources for each value.

Table A2-1. Cost-share of farm-retail products for soybean-based food

	Baking oil	Margarine	Cooking oil	Remaining oil	Plant-based protein food
Soybean	-	-	-	-	0.50[1]
Soybean meal	-	-	-	-	0.50[1]
Soybean oil	0.02	0.10	0.54	0.02	-

[1] Author's assumption

Data: Lusk (2022)

Table A2-2. Cost-share of farm-retail products for feed grains (16/17 ~ 20/21 Average)

	Dairy cattle	Beef cattle	Hog	Poultry bird	Hens
Soybean meal	0.05	0.01	0.14	0.19	0.25
Corn	0.06	0.09	0.33	0.15	0.20

Data: USDA NASS, Value of production (16/17~20/21)
USDA ERS, Oil Crops Yearbook, Table 4 (16/17~20/21)
USDA ERS, Feed Grains Yearbook, Table 30 (16/17~20/21)
USB Market View database (16/17~20/21)

Table A2-3. Cost-share of farm-retail products for the livestock sector (16/17 ~ 20/21 Average)

	Dairy	Beef	Pork	Poultry	Eggs
Dairy cattle	0.33	-	-	-	-
Beef cattle	-	0.53	-	-	-
Hog	-	-	0.31	-	-
Poultry bird	-	-	-	0.43	-
Hens	-	-	-	-	0.58

Data: USDA NASS, Value of production (16/17~20/21)
USDA ERS, Oil Crops Yearbook, Table 4 (16/17~20/21)
USDA ERS, Feed Grains Yearbook, Table 30 (16/17~20/21)
USB Market View database (16/17~20/21)

Table A2-4. Corn use and quantity shares for various usage (16/17 ~ 20/21 Average)

		Disappearance (Million *bu*)	Quantity Share		
Corn		14,504	1.00		
	Food and Industrial use	6,669	0.46		
	Export	2,265	0.16		
	Seed	30	0.002		
	Feed	5,540	0.38	Dairy cattle	0.11
				Beef cattle	0.22
				Hog	0.31
				Poultry bird	0.24
				Hens	0.08

Data: USDA ERS, Feed Grains Yearbook, Table 4 and Table 31 (16/17~20/21)
USDA ERS, Feed Grains Yearbook, Table 30 (16/17~20/21)

Table A2-5. Corn oil use and quantity shares for various usage (16/17 ~ 20/21 Average)

		Usage (Million pounds)	Quantity Share
Corn oil		5,823	1.00
	Export	666	0.11
	Biofuel	2,323	0.40
	Edible oil	2,834	0.48

Data: USDA ERS, Oil Crops Yearbook, Table 33 (16/17~20/21)

Table A2-6. Supply and substitution elasticity

	Price of Soybean	Soy oil	Soy meal	Corn
Soybean	0.26[1)]	-	-	-
Soy oil	-1.07[2)]	0.51[2)]	0.83[2)]	-
Soy meal	-1.02[2)]	0.45[2)]	0.79[2)]	-
Corn	-	-	-	0.29[1)]
Substitution between Soy and Corn for Feed		0.24[3)]		

Data: [1)] Hendricks, Smith, and Sumner (2014)
[2)] Lusk (2022)
[3)] Hertel and van der Mensbrugghe (2016)

Table A2-7. Demand elasticity for soybean and corn

	Price of Export	Seed	Food: Soymilk	Food: Plant-based protein food
Soybean	-1.45[1)]	-	-	-
Soybean residuals	-	-1[2)]	-1[2)]	-1[2)]
Corn	-1.64[1)]	-1[2)]	-1[2)]	

Data: [1)] Reimer, Zheng, and Gehlhar (2012)
[2)] Author's assumption

Table A2-8. Demand elasticity for soy-crushed

	Price of Soybean	Soy oil	Soy meal
Soy-crushed	-1.03	0.46	0.81-

Data: Lusk (2022)

Table A2-9. Demand elasticity for soy oil, soy meal, and corn oil

	Price of Export	Industrial use	Biofuel	Edible oil: Cooking oil	Edible oil: Baking oil	Edible oil: Margarine	Edible oil: Other	Soy-based food
Soy oil	-1.29[1)]	-0.50[2)]	-0.13[3)]	-0.25[4)]	-0.25[5)]	-0.50[4)]	-0.25[4)]	-
Corn oil	-1.29[5)]	-	-0.13[3)]		-0.25[5)]			-
Soy meal	-1.49[1)]	-	-		-			-0.25[5)]

Data: [1)] Uri et al. (1994)
[2)] Kojima et al. (2016)
[3)] Schmitz et al. (2007)
[4)] Yen et al. (2002)
[5)] Author's assumption

Table A2-10. Demand elasticity for edible oil

	Price of				
	Soy oil				Corn oil
	Cooking oil	Baking oil	Margarine	Other	
Cooking oil	-0.82	-	-	-	0.14
Baking oil	-	-0.82	-	-	0.14
Margarine	-	-	-0.82	-	0.14
Other soy oil	-	-	-	-0.82	0.14
Corn oil	0.52	0.52	0.52	0.52	-2.05

Data: Lusk and Son (2023)

Table A2-11. Own price elasticity for livestock inputs

Dairy cattle	-1.40
Beef cattle	-0.60
Hog	-0.47
Poultry birds	-0.49
Hens	-0.25

Data: Lee et al. (2022)

Table A2-12. Demand elasticity for livestock products and plant-based protein food

	Price of Beef[1)]	Pork[1)]	Poultry[1)]	Eggs[1)]	Plant-based protein food[1)]	Dairy[2)]	Soy milk[2)]
Beef	-0.67	0.09	-0.60	-0.60	-0.04	-	--
Pork	0.21	-1.36	-0.19	-0.19	0.04	-	-
Poultry	-0.30	0.07	-0.38	-0.38	0.07	-	-
Egg	-0.30	0.07	-0.38	-0.38	0.07	-	-
Plant-based protein food	0.30	1.43	-1.48	-1.48	-1.23	-	-
Dairy	-	-	-	-	-	-0.95	-0.01
Soy milk	-	-	-	-	-	-0.53	-0.26

Data: [1)] Tonsor and Bina (2023)
[2)] Lusk and Son (2023)