EXTENSION OF AN EQUILIBRIUM DISPLACEMENT MODEL: RELAXING THE FIXED PROPORTION ASSUMPTION AND RECOVERY OF SHOCKS UNDER OBSERVED EQUILIBRIUM

By

MIYEON SON

Bachelor of Arts in Economics
Kyungpook National University
Daegu, South Korea
2008

Master of Science in Economics
Kyungpook National University
Daegu, South Korea
2010

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Dissertation Approved:

Dr. Dayton M. Lambert

Dissertation Adviser

Dr. Wade B. Brorsen

Dr. Lixia H. Lambert

Dr. Lan Zhu

Name: MIYEON SON

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The goal of this research is to extend a conventional equilibrium displacement model (EDM) to one that permits substitution between inputs. The empirical example evaluates economic shocks and their effects on social welfare for the United States (US) food industry linking 24 agricultural commodities and nine retail food products markets. Lusk (2017) and Okrent and Alston (2012)'s (LOA) EDM is used to achieve the research objectives.

The first essay evaluated the effects of the Coronavirus Food Assistance Program (CFAP) on producer and consumer surplus in the US food industry. The LOA-EDM is extended to accommodate constant elasticity of substitution (CES) production technology; thereby relaxing the fixed proportion technology assumption of the LOA-EDM. Findings indicate that CFAP payments not only distributed benefits to producers of various food commodities but also to food consumers via lower food prices. Allowing for input factor substitution resulted in less conservative (larger) estimates of the distributional impacts of CFAP policy on social welfare. Overall, results suggest that welfare measures may be underestimated when an EDM employs fixed proportion technology.

The second essay develops a method for employing an EDM to estimate the effects of inflation on welfare measures. Year-over-year changes in price inflation rates reflect changes in demand and supply. Unknown are the underlying shocks driving inflationary trends. This complicates the estimation of the impacts inflationary trends have on consumer and producer surplus. The LOA-EDM is recast of as an 'Equilibrium Replacement Model' (ERM), which recovers the implied shocks that lead to observed proportional changes in prices and quantity demanded throughout the food sector. The shocks are regressed against gross domestic product and energy prices to establish a relationship between these macroeconomic variables, the estimated shocks, and changes in welfare over 1993 to 2019. That is, given a percent change in a macroeconomic variable, the percent change in a sector-specific shock can be determined and then applied to find corresponding changes in welfare. The results show that social welfare changes caused by shocks in the food sector have risen continuously, and the retail food market is more influenced by changes in macroeconomic variables than the agricultural market.

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INTRODUCTION

The Coronavirus (COVID-19) outbreak in early 2020 is arguably the largest economic shock experienced by the United States (US) economy since the great recession of the 2000s or the depression of the 1930s. COVID-19 caused disruptions in nearly all industry supply chains. These disruptions spilled over into the US agricultural and food industry and experienced an abrupt change in the food consumption patterns of household consumers (Malone, Schaefer, and Lusk, 2020; McFadden et. al., 2021; Ahn and Norwood, 2021; Lusk, Tonsor, and Schulz, 2021). In response to the pandemic, the US Department of Agriculture (USDA) implemented the Coronavirus Food Assistance Program (CFAP). The objective of CFAP was to support farmers in lieu of declines in agricultural prices (Congressional Research Service, 2020). Given the industry linkages between agricultural production and retail foods, the CFAP financial support is expected to directly increase producer surplus and confer downstream benefits to consumers. How were the effects of CFAP policy distributed across agricultural producers, retailers, and consumers? This study hypothesizes that estimation of the surplus effects for producers and consumers varies depending on the substitutability of agricultural inputs in the production of retail foods. This hypothesis is tested using a modified version of Lusk (2017) and Okrent and Alston (2012)'s (LOA) Equilibrium Displacement Model (EDM). The modification entails relaxing the fixed proportion technology assumption of the LOA-EDM by introducing constant elasticity of substitution (CES) technology in the production and processing of agricultural commodities.

Another issue facing the US economy is the high rate of inflation not seen since 1982. Global supply chain disruption caused by the pandemic, pent-up demand, and the money pumped into the economy through the American Rescue Plan has been cited as reasons for the high rate of inflation experienced today. This research introduces an Equilibrium Replacement Model (ERM) as a parametric approach to recover sector-specific shocks driving inflationary trends in year-over-year price inflation for agricultural products and the retail goods made with them. The ERM recasts the structure of the LOA-EDM in a single, fundamental way. Rather than introducing external shocks to determine *ex ante* effects of policies on price-quantity equilibrium, the ERM uses observed year-over-year proportional (percent) changes in prices and quantities to recover the shocks implied by observed price-quantity changes over time. In this way, the ERM is a forensic model designed to recover the magnitude and directions of shocks underlying observed price-quantity changes. In this way, changes in welfare due to inflation, and the shocks that established the new inflation equilibrium, can be parametrically determined. The ERM has advantages over econometric models (e.g., structural vector autoregression models) in that it does not require model specifications and is not rely on the econometric model assumptions.

Introducing CES technology into the ERM is expected to moderate the impact of price changes by changing the producer share of costs. An interesting application regresses estimated shocks for each sector on macro-economic variables, namely Gross Domestic Product (GDP) and Energy Price Index (EPI), to determine the relationships between these variables and recovered shocks. Changes in consumer surplus (CS) and producer surplus (PS) due to changes in GDP and EPI are calculated using the established relationship between the macroeconomic variables and the shocks. CS and PS cannot be calculated absent any information on the magnitude and direction of shocks. A change in a shock corresponds with a change in a macroeconomic variable. Given the change in a shock due to a change in a macroeconomic variable, one can link the two to changes in aggregate welfare.

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CHAPTER II

RELAXING THE FIXED PROPORTION ASSUMPTION OF AN EQUILIBRIUM DISPLACEMENT MODEL: AN EMPIRICAL EXAMINATION OF CFAP PAYMENTS AND THE US FOOD SECTOR

Abstract

The Lusk (2017) and Okrent and Alston (2012)’s equilibrium displacement model (LOA-EDM) is extended to accommodate constant elasticity of substitution (CES) production technology, thereby relaxing the fixed proportion technology assumption for primary food production and processing. The EDM-CES is applied to evaluate the effects of the Coronavirus Food Assistance Program (CFAP) to support farmers who suffered from agricultural price declines caused by the Coronavirus disease outbreak. Findings indicate that CFAP support conferred benefits to agricultural producers through lower input prices and to food consumers via lower food prices. The results suggest that more benefits of agricultural price support accrue to consumers when assuming the fixed proportion of technology. In contrast, when allowing substitution between agricultural commodities, the benefits of CFAP support for producers increase as food processors increase the input of low-priced agricultural products, which alleviates some of the declines in agricultural prices.

Introduction

In response to the coronavirus (COVID-19) pandemic, the US Department of Agriculture (USDA) implemented two rounds of the Coronavirus Food Assistance Program on May 21, 2020 (CFAP-1) and September 22, 2020 (CFAP-2) (Congressional Research Service, 2020). CFAP provisions provided financial assistance to agricultural producers to offset higher input costs and circumvent supply chain bottlenecks (Congressional Research Service, 2020). For CFAP-1, program commodities were those that experienced price declines of 5% or more. CFAP-2 expanded the program commodities included under CFAP-1. For commodities that lacked price data, program-eligible commodities included those that had acres planted data in 2020 or had sales value data in 2019 (Congressional Research Service, 2020). The USDA paid out $18.8 billion during CFAP-1, with an additional $11.8 billion following shortly after under CFAP-2.

CFAP was an immediate government response to the agricultural price drop. CFAP round one implemented payment for 80% of the price drop for products that fell more than 5% in price based on from January to April 2020. Price-loss payments were based on the quantity sold during the first quarter of 2020, and market-cost payments were based on their maximum unpriced inventory from April to May 2020. CFAP round two payments were based on the price decline from January to July 2020. For eligible crops, the payment rate is to be applied to 2020-planted acres of the crop, and for livestock, payments are to be based on the maximum owned inventory on a date selected by the producer between April and August 2020. Prompt government relief for sales and inventory in 2020 is expected to have affected the supply and price of agricultural products.

The objective of this study is to extend a conventional equilibrium displacement model (EDM) by relaxing the fixed proportion technology assumption by introducing constant elasticity of substitution (CES) technology in agricultural production. The effects of CFAP payments are evaluated using EDM-CES and compared to the effects under the fixed proportion technology assumption. There are two main contributions of this research. First, the study estimates the effects of CFAP payments on social welfare by calculating changes in retail-food consumer surplus as well as agricultural producer surplus caused by CFAP payments to support farmers. Lusk (2017) and Okrent and Alston (2012)'s (LOA) EDM is used to estimate changes in producer and consumer welfare following CFAP implementation. Payments supporting farmers are expected to directly benefit agricultural producers, but consumers are also expected to have also benefitted, given the links between the supply of agricultural inputs and demand for retail food.

The second contribution is methodological. Many conventional EDMs assume a fixed proportion, or Leontief, production technology, including LOA's EDM. This assumption may overestimate the effects of policies or shocks because it assumes that producers cannot change the input mix when the input price changes. This occurs because one input cannot be substituted for another in the production of a good under the assumption of fixed proportions technology. The LOA-EDM is modified to accommodate CES production technology along the retail food supply chain. CES production technology relaxes the fixed proportion technology assumption by allowing substitution between productive factors as the relative prices of inputs change while holding output constant (Chambers, 1988). Compared to the fixed proportion assumption, CES production technology permits shocks experienced in one sector to be absorbed by, or distributed over, other sectors. As a result, the distributional effects of shocks and their concomitant changes in social welfare measures will be different in magnitude and direction. The sensitivity of CES production technology to elasticities of substitution between agricultural commodities is demonstrated by analyzing how the quantity and price of agricultural commodities and the producer and consumer surplus change depending on the degree of substitution allowed.

Literature Review

Equilibrium displacement models (EDM), also called multi-market models (Sadoulet and de Janvry, 1995), have been used extensively to estimate the distributional effects of demand- or supply-side policies or other exogenous shocks such as weather or increased demand on markets and their concomitant changes in aggregate social welfare. Sumner and Wohlgenant (1985) first introduced the term "equilibrium displacement modeling," but the earliest EDM formulation is generally attributed to Muth (1964). Muth introduced a system of reduced-form equations that characterized the equilibrium conditions of a multi-sector economy. Gardner (1975), and later Wohlgenant (1989), extended Muth's EDM to investigate the impact of demand, weather, and taxes on the farm-retail price spread with two factors of food production; marketing and agricultural inputs. More recently, Okrent and Alston (2012) developed an EDM to analyze the impact of food subsidies and taxes for obesity on food consumption, body weight, and social welfare. Lusk (2017) extended Okrent and Alston (2012)'s EDM to determine the effects of removing subsidized crop insurance on retail markets.

With the exceptions of Gardner (1975) and Wohlgenant (1989), most EDM applications assume a fixed proportion production technology. Under the fixed proportion assumption, a decrease in the use of input due to an increase in its cost leads to a proportionate decrease in output. This means the elasticity of substitution between factors of production is zero, meaning that the substitution of one input for another is not possible. Relaxing the assumption of fixed proportion technology requires information on how the ratio of two factors of production changes with a concurrent change in the price ratio of the two inputs. Elasticities of substitution (σ) characterize these relationships, providing information on how producers will adjust their input mix given a change in relative prices and the capacity to switch one input for another (Chambers, 1988).

The use of CES technology in EDM production functions is not new. Gardner (1975) acknowledged the limitations of the fixed proportion technology assumption and introduced substitution potential between marketing and agricultural inputs. Holloway (1991), Azzam (1998), and Kinnucan (2003) extended Gardner's (1975) model to develop a conceptual framework that allowed for imperfect competition. Kinnucan (1997) covered the range of substitution elasticity related to the US food system using Leontief and Cobb-Douglas production technologies in marketing. Kinnucan (2003) later used the substitution elasticities to form the CES function in EDM to investigate the optimal generic advertising in an imperfect market.

The standard CES production function was first introduced by Arrow et al. (1961). The CES production function is:

(1) $Y = A\left[\theta \cdot x_1^{-\rho} + (1-\theta) \cdot x_2^{-\rho}\right]^{-\frac{1}{\rho}}$

where A is a firm efficiency parameter, θ is the cost share parameter, and ρ is the degree of substitutability of inputs. The elasticity of substitution between x_1 and x_2 is $\sigma = \frac{1}{1+\rho}$. The elasticity of substitution (σ) can be any number between zero and infinity (Figure 2.1). The extreme case of fixed proportions, or Leontief technology, has L-shaped isoquants when $\sigma = 0$. In this case, farm demand is less elastic than retail demand. In a market power study, the implications are that market power effects on derived demand for farm inputs tend to be more pronounced, which in turn exaggerates the effect of market power on welfare (Gardner 1974; Kinnucan 1997; Kinnucan 2003). At the other extreme is a linear production technology that has straight-line isoquants, which occurs when $\sigma = \infty$. Cobb-Douglas production technology lies between these two extremes, with gently sloping convex isoquants when $\sigma = 1$. When $\sigma = 1$, changes in demand for retail food do not affect the farmer's share of retail food expenditure. When $\sigma > 1$, an increase in demand for retail food increases the farmer's share of food expenditure. The opposite effect occurs when $\sigma < 1$ (Gardner 1974).

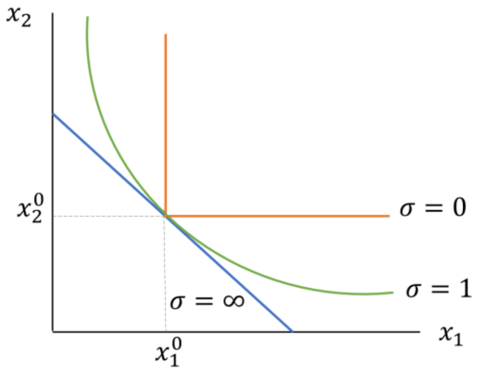

Figure 2.1 CES production function isoquants

The specific case of a substitution relationship between farm products and marketing inputs discussed in the market power literature can be extended to inter-agricultural commodity input substitution elasticity to produce retail food products. The substitutability between agricultural commodities for food processing or animal feeding has been previously documented (Roy and Ireland, 1975; Marsh, 2005; Sands, Jones, and Marshall, 2014; Suh and Moss, 2017; Williams and Capps, 2020). Okrent and Alston (2012) modeled the linkages between farm commodities and retail markets assuming that one or more farm commodities and one or more marketing inputs are used to produce a particular retail food. In the retail food industry, treating the quantity of agricultural commodities as a factor of production has the advantage of aggregating the output supply and input demand functions of individual farms to produce theoretically consistent behavioral relationships. The parametric limitations of farm behavior and market clearance conditions provide a theoretically consistent framework for measuring the effect of changes in consumer demand, farm and marketing input supply on retail, and farm product prices (Wohlgenant, 1989). When substitutability between commodities is not considered, price effects resulting from external shocks can be overestimated. For example, the aggregated retail food product ‘meat’ is produced with multiple farm commodities, including beef, pork, poultry, fish, in addition to marketing inputs (e.g., packaging, wrapping, advertising). When production technology is fixed-proportion, the cost of producing meat in response to a change in input prices remains unchanged. By allowing substitution between different livestock inputs, costs will change, but costs also depend on substitution elasticity between livestock as inputs. In other words, when input prices change, producers will increase the use of relatively less expensive inputs to maintain the same level of output, which results in a change in the cost-shares of production. When the fixed proportion assumption is relaxed, producers are expected to respond to exogenous shocks by rebalancing the cost shares of individual inputs towards a less costly mix.

Methods and Procedures

Structure of the Equilibrium Displacement Model

Lusk (2017)’s EDM links retail food markets and food-related farm commodity markets (Figure 2.2). This EDM consists of final demands for nine retail foods and the supply of 24 farm commodities used in the producing final products. Final food products include (1) cereals and bakery, (2) meat, (3) eggs,

(4) dairy, (5) fruits and vegetables, (6) other foods, (7) non-alcoholic beverages, (8) alcoholic beverages, and (9) Food Away from Home (FAFH) [1]. The model includes the supply of six farm products including (1) oil crops, (2) grains, (3) cattle, (4) pork, (5) dairy, and (6) poultry and eggs that are derived from the supply of (13) soybeans, (14) corn, (15) wheat, (16) rice, (17) barley, (18) oats, (19) sorghum, (20) cattle inputs, (21) pork inputs, (22) dairy inputs, (23) poultry inputs, and (24) egg inputs. Supply of the other six farm products, which are (7) vegetables and melons, (8) fruits and tree nuts, (9) sugar cane and sugar beet, (10) peanuts, (11) fish, and (12) marketing inputs, are not derived from the supply of other farm products but are directly involved in the final retail food production[2]. The total supply of feed grains like soybean, corn, wheat, rice, barley, oats, and sorghum are used for food processing, exports, and animal feeding, respectively. Corn is also used to produce ethanol. Feed grains and animal inputs for cattle, pork, dairy, poultry, and eggs are used in the production of livestock commodities.

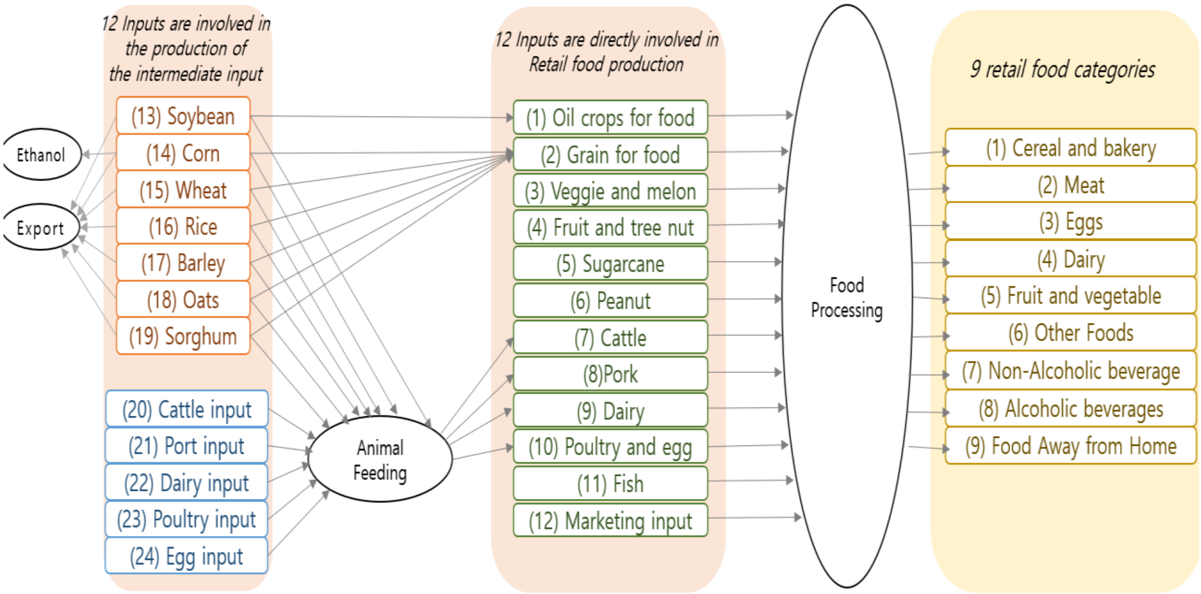

Figure 2.2 Overview of Lusk (2017)'s equilibrium displacement model

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[1] Food Away from Home (FAFH) means all food produced and consumed away from home such as food purchased at restaurants.

[2] Numbers in parentheses before the detailed list of retail goods and agricultural commodities indicate the subscripts, which appear in the model equations, which follow.

The empirical approach used to measure the effects of CFAP on welfare relies on the assumptions typically maintained in EDM studies. That is, the production technology is known, returns to scale are constant (CRS), the market is completely competitive, and retail firms maximize profit. The assumption that the production technology is ‘fixed proportion’ (that is, Leontief) is maintained for the moment.

There are nine retail demand equations in log-differential form:

$(2)-(10)\ \hat{q}_i = \sum_{j=1}^{9} \eta_{ij} \cdot \hat{p}_j \qquad \text{for } i = 1 \text{ to } 9$

where $\hat{q}_i$ is the proportionate change in the quantity of retail good i, $\hat{p}_i$ is the proportionate change in the retail price of good i, and η_{ij} are own- and cross-price elasticities of demand for retail good i with respect to the price of good j. Under the CRS assumption, changes in the price of retail goods are:

$(11)-(19)\ \hat{p}_i = \sum_{k=1}^{12} SR_k^i \cdot \widehat{w}_k \qquad \text{for } i = 1 \text{ to } 9$

where SR_k^i is the input k's share of the total cost to produce retail good i and $\widehat{w}_k$ is the proportionate change in the price of input commodity k.

The six commodities including vegetables, fruits and tree nuts, sugar cane and sugar beet, peanuts, fish, and marketing inputs, are directly supplied to consumers. Changes in these farm commodity outputs are:

$(20)-(25)\ \hat{x}_k = \varepsilon_k \cdot (\widehat{w}_k + \varphi_k) \qquad \text{for } k = 7\ to\ 12$

where $\hat{x}_k$ is the proportionate change in the supply of input commodity k, ε_k is the own-price elasticity of supply for commodity k, and φ_k is an exogenous supply shifter which is interpreted as the effect of interventions or external shocks on output.

The supply shares of crops used for food (F), exports (T), animal feed (A), and ethanol production (E) determine the demand for feed grains as follows:

$(26-32)\ \hat{x}_k = S_k^F \cdot \hat{x}_k^F + S_k^T \cdot \hat{x}_k^T + S_k^A \cdot \hat{x}_k^A + S_k^E \cdot \hat{x}_k^E \qquad \text{for } k = 13 \text{ to } 19$

where $S_k^F, S_k^T, S_k^A, S_k^E$ are the quantity share of feed grains used to produce food, exports, animal feed, and ethanol respectively.

Changes in the total demand for each feed grain are:

$(33-39)\ \hat{x}_k = \varepsilon_k \cdot (\widehat{w}_k + \varphi_k) \qquad \text{for } k = 13 \text{ to } 19$

whereas the changes in demand for the export of each feed grain are:

$(40-46)\ \hat{x}_k^T = \eta_{k,T} \cdot \widehat{w}_k \qquad \text{for } k = 13 \text{ to } 19$

with $\eta_{k,T}$ the own-price elasticity for export demand of the k^{th}feed grain. The change in corn demand for ethanol production is:

$(47)\ \hat{x}_{14}^E = \eta_{14,E} \cdot \widehat{w}_{14}$

with $\eta_{14,E}$ the own-price elasticity of demand for corn by ethanol producers.

Soybean used to produce food goes to oil crops used in food processing, and thus it is assumed that the demand for soybean to make food is determined by oil-crop food demand. From this relationship, the demand equation of soybean for food is:

$(48)\ \hat{x}_{13}^F = \hat{x}_1$

with the corresponding inverse supply of soybeans to oil crops:

$(49)\ \widehat{w}_1 = S_{1,13} \cdot \widehat{w}_{13}$

where $S_{1,13}$ is the cost share of soybeans in the total cost of producing oil crops. Changes in the inverse supply of grains to make food products come from feed grains such as corn, wheat, rice, barley, oats, and sorghum. The food grain supply equation is:

$(50)\ \widehat{w}_2 = \sum_{k=14}^{19} S_{2,k} \cdot \widehat{w}_k$

where $S_{2,k}$ is the cost share of each feed grain in the total cost of producing grains for food processing. The animal feeding sector consists of multiple inputs including feed grains and animal inputs and multiple outputs including cattle, pork, dairy, poultry, and eggs. The inverse supply equations for the livestock food sector are:

$(51-54)\ \widehat{w}_k = \sum_{m=13}^{24} SA_k^m \cdot \widehat{w}_m \qquad \text{for } k = 3 \text{ to } 6$

where $\widehat{w}_k$ are proportionate changes in input prices and SA_k^m is the cost share of the total animal inputs of producing livestock commodity k attributable to animal feeding input m. In the equations, the k aliases m. Changes in derived demands for animal inputs are:

$(55-59)\ \hat{x}_k = \sum_{m=3}^{6} SM_k^m \cdot \hat{x}_m \qquad \text{for } k = 20 \text{ to } 24$

where SM_k^m is the quantity share of the total production of animal feeding input k used by livestock commodity m. Changes in the demand for animal inputs are

$(60-64)\ \hat{x}_k = \varepsilon_k \cdot (\widehat{w}_k + \varphi_k) \qquad \text{for } k = 20 \text{ to } 24.$

This model assumes a Leontief production function because the structure of the equations does not consider the substitutability between agricultural inputs, but only estimates the change in agricultural supply by price and cost share of the input.

Nested CES Production Technology

The nested CES function for multiple inputs is an extension of the two input CES function (see Equation (1)) which allows for multiple levels of substitutability between inputs and unrestricted composition of the nested structures. To represent a nested CES function, a nesting structure for the inputs should be defined. Look first at the simplest example of a two-level and three-input CES function. One feasible nesting structure is represented by $((x_1, x_2), x_3)$ and the nested CES function is:

$$(65)\ Y = A\left[\theta \cdot (\beta \cdot x_1^{-\rho_1} + (1-\beta) \cdot x_2{}^{-\rho_1})^{\frac{\rho}{\rho_1}} + (1-\theta) \cdot x_3{}^{-\rho}\right]^{-\frac{1}{\rho}}$$

where A is a firm efficiency parameter, θ is the cost share parameter between (x_1, x_2) and x_3, β is the cost share parameter between x_1 and x_2, and ρ_1, ρ are the degree of substitutability of two levels, and Y is a composite output. The elasticity of substitution between (x_1, x_2) and x_3 is $\sigma = \frac{1}{1+\rho}$ and the elasticity of substitution between x_1 and x_2 is $\sigma_{12} = \frac{1}{1+\rho_1}$.

Figure 2.3 summarizes the EDM with CES production technology. The individual commodities included in each of these composite inputs are assumed to be separable. In Figure 2.2, sigma (σ) notates the elasticity of substitution. The introduction of nested CES production technology relaxes the fixed proportion technology assumption for farm commodities. Substitution effects are introduced (1) between farm output and marketing inputs (σ), (2) between grains and livestock outputs (σ^{ag}), (3) between oil crop and grains (σ^{c}), and (4) between livestock outputs (σ^{l}). For grains, it is assumed that food grains are substitutes for each other (σ^{f}), and feed grains can also be substitutes among themselves (σ^{a}). Except for the grain and livestock sectors, the EDM with CES technology assumes there are no substitutes for vegetables and melons, fruits and tree nuts, sugar cane and sugar beet, peanuts, and fish. Similarly, cattle, pork, dairy, poultry, and egg inputs are not substitutes for each other. The substitution elasticity equals ‘0’ for these cases, meaning that their production nest is Leontief.

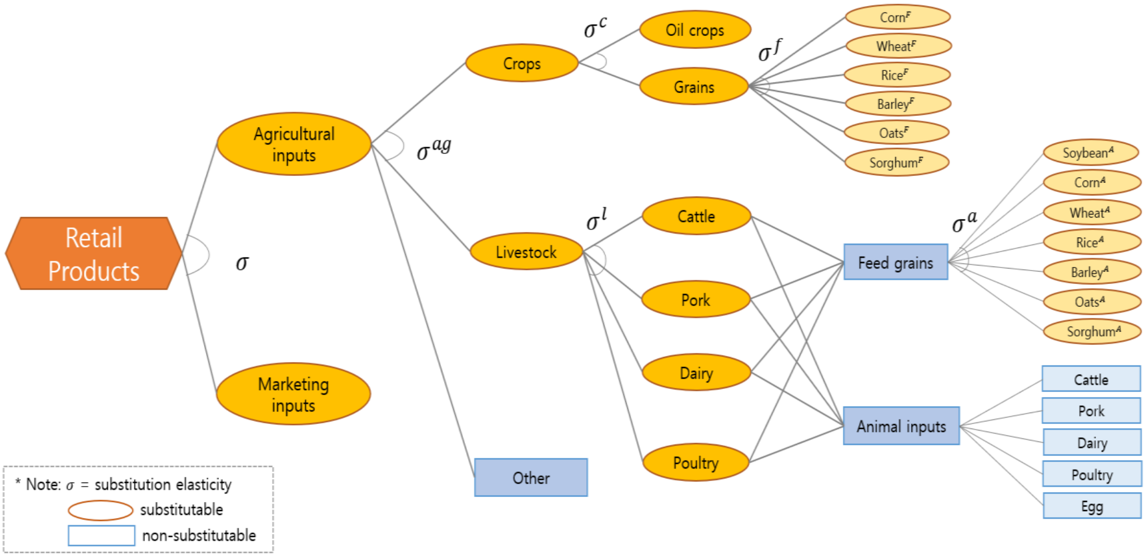

Figure 1.3 Nested CES production and agricultural commodity market

When substitution between goods is not possible, then changes in demand for farm commodities are estimated as the sum product of the cost-shares of the k commodities used by the retail sector i and changes in output:

$$(66-70)\ \hat{x}_k = \sum_{i=1}^{9} SC_k^i \cdot \hat{q}_i \qquad \text{for } k = 7 \text{ to } 11, \text{ with } \sum_{i=1}^{9} SC_k^i = 1$$

For substitute commodities in the retail food sector, it is postulated that output is produced with CES technology by combining two inputs into a composite putput; agricultural inputs and marketing inputs. Change in the demand for agricultural commodity aggregate ($\hat{x}_i^{ag}$) to produce retail commodity i after admitting substitution between agricultural and marketing inputs is:

$(71-79)\ \hat{x}_i^{ag} = \ \hat{q}_i + \sigma \cdot (\hat{p}_i - \hat{p}_i^{ag}) \qquad \text{for } i = 1 \text{ to } 9$

where $\hat{p}^{ag}$is the proportionate change in the composite agricultural price, and σ is the elasticity of substitution between composite agricultural products and marketing inputs (Figure 2.3). The proportionate change in the composite price is:

$(80-88)\ \ \hat{p}_i^{ag} = \sum_{k=1}^{11} SR_k^i \cdot \widehat{w}_k \qquad \text{for } i = 1\ to\ 9$

where SR_k^i is the cost share of producing retail good i attributable to the kth agricultural output. The second composite actor of production is marketing inputs. The change in demand for marketing inputs is:

$(89)\ \hat{x}_{12} = \sum_{i=1}^{9} SC_{12}^i \cdot \hat{q}_i + \sigma \cdot (\hat{p}_i - \widehat{w}_{12})$

where SC_{12}^i is the cost share of marketing inputs used by retail product i.

The aggregate agricultural commodity is produced using CES technology by combining crop and livestock inputs. Changes in the total crop and livestock demand by retail sector i are, respectively:

$(90-98)\ \ \hat{x}_i^{crop} = \ \hat{x}_i^{ag} + \sigma^{ag} \cdot (\hat{p}_i^{ag} - \hat{p}_i^{crop}) \qquad \text{for } i = 1 \text{ to } 9$

$(99-107)\ \ \hat{x}_i^{anim} = \ \hat{x}_i^{ag} + \sigma^{ag} \cdot (\hat{p}_i^{ag} - \hat{p}_i^{anim}) \qquad \text{for } i = 1 \text{ to } 9$

where σ^{ag} is the elasticity of substitution between crop and livestock outputs (Figure 2.3), and $\hat{p}_i^{crop}$ and $\hat{p}_i^{anim}$ are the proportionate change in the composite prices for crop and livestock products used by the retail sector i, respectively. These terms are calculated as:

$(108-116)\ \ \hat{p}_i^{crop} = \sum_{k=1}^{2} SR_k^i \cdot \widehat{w}_k \qquad \text{for } i = 1 \text{ to } 9$

$(117-125)\ \ \hat{p}_i^{anim} = \sum_{k=3}^{6} SR_k^i \cdot \widehat{w}_k \qquad \text{for } i = 1 \text{ to } 9$

Changes in the demand for oil crop and grain commodities are:

$$(126-127)\ \hat{x}_k = \sum_{i=1}^{9} SC_k^i \cdot \hat{x}_i^{crop} + \sigma^c \cdot (\hat{p}_i^{crop} - \widehat{w}_k) \qquad \text{for } k = 1, 2$$

where SC_k^i and SC_2^i are the share of the total cost of kth farm product used by the retail sector i and σ^c is the elasticity of substitution between oil crop and grains (Figure 2.3). Similarly, changes in the demand for livestock commodities are:

$$(128-131)\ \hat{x}_k = \sum_{j=1}^{9} SC_k^i \cdot \hat{x}_i^{anim} + \sigma^l \cdot (\ \hat{p}_i^{anim} - \widehat{w}_k) \qquad \text{for } k = 3\ to\ 6$$

where σ^l is the substitution elasticity between cattle, pork, dairy, poultry, and eggs (Figure 2.3).

For grains other than soybean, their demand for food processing is derived as a function of aggregate demand for grains and the substitution among grain prices:

$$(132-137)\ \hat{x}_k^F = \hat{x}_2 + \sigma^f \cdot (\ \hat{p}^{cropf} - \widehat{w}_k) \qquad \text{for } k = 14 \text{ to } 19$$

where σ^f is the elasticity of substitution between crops for food processing, and $\hat{p}_j^{cropf}$ is the composite price for crops for food processing (Figure 2.3). The change in the composite price for grains for food processing is:

$$(138)\ \hat{p}^{cropf} = \sum_{k=14}^{19} S_k \cdot \widehat{w}_k$$

where S_k are cost shares for corn, wheat, rice, barley, oats, and sorghum. Changes in demand for feed crops, including soybeans, are derived from the aggregate demand for feed grains and the substitution possibility between them:

$$(139-145)\ \hat{x}_k^A = \sum_{m=3}^{6} SM_k^m \cdot \hat{x}_m + \sigma^a \cdot (\ \hat{p}^{feedg} - \widehat{w}_k) \qquad \text{for } k = 13 \text{ to } 19$$

where SM_k^m is the quantity share of the total production of animal feed grain k used by the livestock sector m and σ^a is the elasticity of substitution between feed grains (Figure 2.3). The change in the composite price for grains feeding animals is:

$$(146)\ \hat{p}^{feedg} = \sum_{k=13}^{19} \sum_{m=3}^{6} SA_k^m \cdot \widehat{w}_k$$

where SA_k^m is the cost share of the total production of livestock commodity m contributed by animal-feed grain k.

The EDM model with CES technology consists of 144 endogenous variables, and a conformable 144 × 144 matrix of technical coefficients. The sensitivity of the CES-EDM to the magnitude of substitution is investigated by comparing the results of the Leontief-EDM to those of the CES-EDM under different elasticity of substitution assumptions. Three CES models are considered, each with different assumptions pertaining to the degree of substitutability between inputs; CES-1, CES-2, and CES-3. CES-1 is the most restrictive in terms of input substitutability. CES-2 and CES-3 doubled and tripled, respectively, the elasticity of substitution between agricultural inputs. That means, CES-3 is most permissive in terms of input substitutability, and CES-2 is intermediate to CES-1 and CES-3. As the elasticities of substitution between agricultural inputs increase, producers will swap inputs such that costs are minimized. Under the CES technology assumption, price changes are expected to be moderated relative to the EDM with fixed proportion technology. Sources for these elasticities of substation are discussed below.

Welfare Calculations and CES Technology

The change in consumer surplus (ΔCS) following the implementation of CFAP is calculated using Lusk (2017)'s, Okrent and Alston (2012)'s, and Wohlgenant (2011)'s second-order approximation:

$$(145)\ \Delta CS = \sum_{i=1}^{9} -P_{i,0} \cdot Q_{i,0} \cdot \hat{p}_i \cdot \left(1 + 0.5 \cdot \sum_{j=1}^{9} \mathrm{H}_{ij} \cdot \hat{p}_j\right)$$

where $P_{i,0}$ and $Q_{i,0}$ are the prices and demand for retail good i in the initial equilibrium and H_{ij} is the Hicksian compensated elasticity of demand calculated with the Marshallian uncompensated elasticity of demand, expenditure share of the retail product, and expenditure elasticity[3]. An approximation of the change in farm producer surplus (ΔPS) is:

$$(146)\ \Delta PS = \sum_{k=1}^{24} w_{k,0} \cdot x_{k,0} \cdot (\widehat{w}_k + \varphi_k) \cdot (1 + 0.5 \cdot \hat{x}_k)$$

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[3] $\mathrm{H}_{ij} = \eta_{ij} + s_j \cdot \eta_i^E$ with η_{ij} demand elasticity for retail good i with respect to the price of good j, s_j expenditure share of retail good j, and η_i^E expenditure elasticity of retail good i.

where $w_{k,0}$ and $x_{k,0}$ are the price and demand farm commodity k at the initial equilibrium, and φ_k is an economic shock affecting the farm sector k. Grains, including soybean, corn, wheat, rice, barley, oats, and sorghum, are used for food processing, export, and animal feeding. Corn is also used for ethanol production. Therefore, changes in foreign consumer surplus (ΔIS) accruing to importers of feed grains and changes in ethanol producer surplus (ΔETH) are, respectively:

$$(147)\ \Delta IS = -\sum_{k=13}^{19} w_{k,0} \cdot x_{k,0}^{T} \cdot \widehat{w}_k \cdot (1 + 0.5 \cdot \hat{x}_k^{T})$$

$$(148)\ \Delta ETH = -w_{k0} \cdot x_{13,0}^{E} \cdot \widehat{w}_k \cdot (1 + 0.5 \cdot \hat{x}_{13}^{E})$$

where $w_{k,0} \cdot x_{k,0}^{T}$ is the export value of grain commodity k in the initial equilibrium and $w_{k0} \cdot x_{13,0}^{E}$ is the value of ethanol production, also evaluated at the initial equilibrium. The CFAP payment application was closed, and expenditure on the program has been executed by the government. Therefore, the government expenditure data paid for CFAP is used for the change in government revenue for welfare analysis.

Data

The CFAP program covered 207 agricultural commodities. This study focuses on the food supply and retail industries, so payments for 30 non-food commodities among the eligible commodities for CFAP are excluded from the analysis. The non-food commodities include cotton, tobacco, wool, and horticultural products. Table 2.1 summarizes the CFAP payment for food-related and agricultural commodities, along with the ratio of payments to the production value of a commodity. The 177 food commodities included in this analysis were aggregated to 18 agricultural commodity categories consistent with the EDM sectors. The supply of grains and livestock ($k = 1$ to 6) are derived from detailed commodities ($k = 12$ to 24) such as feed grains, beef, pork, dairy, poultry, and eggs. The sum of the CFAP payments to 18 agricultural commodities ($k = 7$ to 24) is used to proxy exogenous supply shocks. For example, CFAP payments to the poultry sector, $258.96 million, are the sum of assistance payments received by the chicken, turkeys, broilers, and other poultry sectors.

Table 2.1. Coronavirus Food Assistance Program (CFAP) payments by commodity

Commodity	CFAP Payment[a] (million $)	Value of Production[b] in 2020 (million $)	Payment as a Share of Value of Production
Oats	73.60	196	0.3750
Cattle	8,398.89	38,622	0.2175
Wheat	1,505.22	9,389	0.1603
Barley	109.99	788	0.1396
Sorghum	240.89	1,768	0.1363
Pork	1,196.02	10,375	0.1153
Corn	6,859.94	64,314	0.1067
Dairy	3,059.87	37,701	0.0812
Soybean	3,395.23	45,732	0.0742
Vegetables & melon	733.47	14,152	0.0518
Peanut	55.51	1,294	0.0429
Rice	99.68	3,314	0.0301
Fruits & tree nut	567.47	28,119	0.0202
Sugar cane & sugar beet	54.01	3,101	0.0174
Poultry	258.96	20,220	0.0128
Eggs	75.29	6,508	0.0116
Fish[c]	88.63	18,274	0.0049

[a] CFAP payments by commodity are the sum of CFAP 1 and CFAP 2, categorized by agricultural commodity category. Detailed data are available from USDA Farmer.gov. (https://www.farmers.gov/coronavirus/pandemic-assistance/cfap1/data, and https://www.farmers.gov/coronavirus/pandemic-assistance/cfap2/data, April 2022 accessed).

[b] The value of production data is as of 2020. Data on the value of production for agricultural commodities are obtained from USDA National Agricultural Statistics Service (NASS) (http://www.nass.usda.gov/Quick_Stats/).

[c] The value of production for fish used the personal consumption expenditures for 'fish and seafood' from the U.S. Bureau of Economic Analysis (https://apps.bea.gov/iTable/index_nipa.cfm).

Implementation of the shocks on the model's equilibrium follows Lusk (2017)'s methodology. The effects of the CFAP payments on consumer demand and prices are calculated as the effects of changes relative to an initial equilibrium. The CFAP shocks represent vertical shifts in the agricultural commodity supply curves and measure changes in marginal costs resulting from the CFAP payments. In this study, the share of total assistance payments to the commodity's values of production are used as supply shocks. For example, the oats supply shock that enters the model, φ_{oats}, is equal to 0.375 (Table 2.1), which is calculated as

$$\frac{\text{CFAP1} + \text{CFAP2}}{\text{value of production in 2021}} = \frac{\$(3.02 + 70.58)\text{ million}}{\$196\text{ million}} = 0.375.$$

Cost Shares and Elasticities

The elasticities and cost shares used in the EDM are from Okrent and Alston (2011) and Lusk (2017). Okrent and Alston (2011) estimated uncompensated elasticities of demand (η_{ij}) and expenditure elasticities using the US Bureau of Economic Analysis (BEA)'s annual personal consumption expenditure data and Fisher-Ideal price indexes (Table 2.2). They also calculated the farm-retail product shares (SR_k^i) and farm-commodity shares (SC_k^i) using the BEA's 2002 Benchmark Input-Output tables (Okrent and Alston, 2012).

Table 2.2. Uncompensated demand elasticities, expenditure elasticities, and expenditure share

Category	1	2	3	4	5	6	7	8	9	Expenditure
1. Cereals & bakery	-0.93	0.04	0.02	0.14	0.13	0.45	-0.04	-0.06	-0.42	0.28
2. Meat	0.02	-0.40	0.05	0.00	0.16	-0.12	-0.09	0.2	0.23	0.64
3. Eggs	0.24	1.00	-0.73	0.66	-0.47	-0.54	0.27	-0.2	0.25	-0.69
4. Dairy	0.16	0.00	0.08	-0.91	-0.09	0.26	0.2	0.17	-0.26	0.97
5. Fruits & vegetables	0.14	0.32	-0.05	-0.07	-0.58	-0.15	0.11	-0.03	0.2	0.27
6. Other foods	0.33	-0.17	-0.04	0.15	-0.11	-0.62	0.05	0	0.12	0.79
7. Non-alcoholic beverages	-0.06	-0.22	0.03	0.21	0.13	0.08	-0.77	0.18	-0.08	0.86
8. Alcoholic beverages	-0.05	0.24	-0.02	0.10	-0.02	0.00	-0.02	-0.12	-0.55	0.50
9. FAFH[a]	-0.15	0.13	0.01	-0.07	0.06	0.05	0.1	-0.5	-0.22	0.84
Expenditure share[b]	0.015	0.026	0.002	0.012	0.014	0.020	0.011	0.022	0.044	-

Source: Lusk (2017), Okrent and Alston (2011).

[a] Food-Away-From-Home.

[b] The sum of expenditure shares for food accounts for 0.166, and the remaining 0.834 is the share of non-food products.

Table 2.3 reports the cost shares of producing retail products attributable to agricultural commodities and are also from BEA input-output tables (BEA, 2007) and compiled by Okrent and Alston (2012). The cost share of marketing inputs accounts for more than 90% of the total cost of producing these products for cereals and bakery, non-alcoholic beverages, alcoholic beverages, and

Food-Away-From-Home (FAFH). Retail food products, such as meat, eggs, and fruits and vegetables, are consumed as products without much processing, so the cost shares of marketing inputs are relatively small compared to other retail foods.

Table 2.3. Cost-share of farm-retail products

Category	Cereal & Bakery	Meat	Egg	Dairy	Fruits & Vegetables	Other Food	Non-Alcoholic Beverage	Alcoholic Beverage	FAFH[a]
1. Oil crop	-	-	-	-	-	0.0619	-	-	0.0027
2. Grain	0.0593	-	-	-	0.0027	0.0345	-	0.0164	0.0038
3. Vegetable & melon	-	-	-	-	0.2722	0.0167	-	-	0.002
4. Fruits &tree nuts	0.0027	-	-	0.0012	0.2062	0.0184	0.0294	0.0213	0.0018
5. Sugar cane & sugar beet	-	-	-	-	-	0.0131	-	-	0.0006
6. Peanut	0.0009	-	-	-	-	0.0210	0.0038	0.0024	0.0010
7. Cattle	-	0.1907	-	-	-	-	-	-	0.0094
8. Pork	-	0.0726	-	-	-	0.0030	-	-	0.0046
9. Dairy	-	-	-	0.2739	-	0.0009	-	-	0.0096
10. Poultry & Eggs	0.0063	0.0923	0.6851	0.0022	0.0006	0.0039	-	-	0.0051
11. Fish	-	0.0638	-	-	0.0039	0.0003	-	-	0.0072
12. Marketing	0.9309	0.5806	0.3149	0.7227	0.5144	0.8264	0.9668	0.9599	0.9523

Source: Calculated by Okrent and Alston (2012) based on 2002 Benchmark I-O Tables (U.S. Department of Commerce, Bureau of Economic Analysis 2007).

[a] Food-Away-From-Home.

Table 2.4 summarizes the cost shares of agricultural commodities used by retail producers, also as indicated by the BEA input-output tables and complied by Okrent and Alston. Each commodity is used in different proportions in the production of retail food products. For example, 85.25% of oil crops are used to produce other food products, while the remaining 14.75% are used to produce FAFH products. Marketing inputs are used in the production of all retail food products, and the marketing inputs cost share used by FAFH is the largest, at 54.69%.

Table 2.4. Cost-share of farm-commodities

Commodity	Cereal & Bakery	Meat	Egg	Dairy	Fruits & Vegetables	Other Food	Non-Alcoholic Beverage	Alcoholic Beverage	FAFH[a]
Oil crop	0	0	0	0	0	0.8525	0	0	0.1475
Grain	0.3812	0	0	0	0.0134	0.3811	0	0.0573	0.1670
Vegetables & melon	0	0	0	0	0.8337	0.1133	0	0	0.053
Fruits & Tree nuts	0.0113	0	0	0.0041	0.6812	0.1347	0.0665	0.0494	0.0528
Sugar cane & sugar beet	0	0	0	0	0	0.8525	0	0	0.1475
Peanut	0.0186	0	0	0	0	0.7665	0.0428	0.0281	0.1440
Cattle	0	0.8374	0	0	0	0	0	0	0.1626
Pork	0	0.7769	0	0	0	0.0313	0	0	0.1918
Dairy	0	0	0	0.7682	0	0.0054	0	0	0.2264
Poultry & Eggs	0.0254	0.6465	0.1517	0.0073	0.0018	0.0270	0	0	0.1403
Fish	0	0.6777	0	0	0.0187	0.0027	0	0	0.301
Marketing	0.0781	0.0849	0.0015	0.0493	0.0335	0.1191	0.043	0.0439	0.5469

Source: Calculated by Okrent and Alston (2012) based on 2002 Benchmark I-O Tables (U.S. Department of Commerce, Bureau of Economic Analysis 2007).

[a] Food-Away-From-Home.

Lusk (2017) used elasticities reported in the literature to parameterize his EDM (Table 2.5). Those values are used here. The elasticities of supply (ε_k), export ($\eta_{k,T}$), and ethanol demand ($\eta_{14,E}$) used by Lusk (2017) are reproduced in Table 2.5. Most elasticities of supply are from Harrington and Dubman (2008), except for fruit and tree nuts, fish, and marketing. The elasticity of supply for fruit and tree nuts is from Chavas and Cox (1995), and that of fish from Okrent and Alston (2012). For the marketing input elasticity of supply, Lusk used an arbitrary value of 10,000 for the elasticity of supply for marketing inputs, which means that the elasticity of marketing inputs is perfectly elastic. The implication is that when considering the benefits relative to the marketing cost, any amount of marketing inputs will be supplied at the prevailing price, but nothing is supplied below this prevailing price. That value is also used here. Export elasticities of demand are from Harrington and Dubman (2008). The ethanol demand elasticity for corn is from Schmitz et al. (2007).

Table 2.5. Elasticities of supply, export demand, and ethanol demand

Commodity	Supply[a]	Export[e]	Ethanol demand[f]
Vegetables & melon	1.26	-	-
Fruits & Tree nuts	1.65[b]	-	-
Sugar cane & Sugar beet	0.96	-	-
Peanut	0.87	-	-
Fish	0.40[c]	-	-
Marketing	10000[d]	-	-
Soybean	1.40	-2.50	-
Corn	1.25	-1.20	-0.13
Wheat	1.27	-0.85	-
Rice	1.22	-2.62	-
Barley	2.35	-0.67	-
Oats	1.51	-3.93	-
Sorghum	3.10	-1.86	-
Cattle	1.07	-	-
Pork	0.79	-	-
Dairy	0.89	-	-
Poultry	1.15	-	-
Eggs	1.04	-	-

Source: Lusk (2017)

[a] Most elasticities of supply are based on Harrington and Dubman (2008).

[b] Chavas and Cox (1995).

[c] Okrent and Alston (2012).

[d] assumed by Lusk (2017).

[e] Harrington and Dubman (2008).

[f] Schmitz et al. (2007).

Farm Commodity Supply and Usage

Lusk (2017) used a five-year average from 2008 to 2012 for farm commodity data. In this study, all the supply and usage data have been updated based on 2020. Changes in the aggregate supply of feed grains are estimated using the share of the crop used for food processing, export, animal feeding, and ethanol production. Data on the quantity share of crop usage for food (S_k^F), export (S_k^T), feed (S_k^A), and ethanol production (S_k^E) are from the oil crop, wheat, rice, and feed grain yearbook published by the U.S. Department of Agriculture, Economic Research Service (USDA-ERS, 2020). The shares of crop usage in Table 2.6 do not sum to one because they do not include other uses, including seed and residual use. As the table suggests, rice and barley are mainly used for food processing (56.8% of rice and 76.4% of barley), while a large share of soybean and wheat supply is exported (49.2% of soybean and 47.0% of wheat). Corn and oats are mainly used to feed animals (37.8% of corn and 45.6% of oats), and 34.1% of the corn supply is used to produce ethanol.

Table 2.6. Share of crop usage for food, export, feed, and ethanol (2020)

Commodity	Food	Export	Feed	Ethanol
Soybean	0.481	0.492	0.027	-
Corn	0.093	0.186	0.378	0.341
Wheat	0.455	0.470	0.045	-
Rice	0.568	0.381	0.043	-
Barley	0.764	0.074	0.138	-
Oats	0.482	0.021	0.456	-
Sorghum	0.024	0.742	0.232	-

Source: U.S. Department of Agriculture, Economic Research Service, Oil Crop Yearbook. Wheat Yearbook, Rice Yearbook, Feed Grains Yearbook. (https://www.ers.usda.gov/data-products/)

The shares of production value for crops to food processing (S_k) are calculated using the supply quantities of feed grains and the share of grain used in food processing (Table 2.7). For example, 48.1% of soybean is used in food processing with respect to oil crop commodities, while 7.5% of corn, 5.4% of wheat, 2.4% of rice, 0.8% of barley, and 0.1% of oats and sorghum are used in food processing with respect to grain commodities. The shares of grain quantity for animal feeding also are from the USDA-ERS's feed grains yearbook (USDA-ERS, 2020). USDA-ERS reports that, of all feed grains used for animal feeding, 26% goes toward feed for cattle, 31.4% for pork, 10.7% for dairy, and 32.5% for poultry and eggs. The feed grains yearbook reports only the share of total grains for each livestock feeding, so it is assumed that these proportions (SM_k^m) are the same for all grains.

Table 2.7. Supply share of crops for food processing and animal feed (2020)

		Feed[c]			
Commodity	Food[a]	Cattle	Pork	Dairy	poultry
Soybean	0.48[b]	0.260	0.314	0.107	0.325
Corn	0.075	0.260	0.314	0.107	0.325
Wheat	0.054	0.260	0.314	0.107	0.325
Rice	0.024	0.260	0.314	0.107	0.325
Barley	0.008	0.260	0.314	0.107	0.325
Oats	0.001	0.260	0.314	0.107	0.325
Sorghum	0.001	0.260	0.314	0.107	0.325

[a] Supply shares of food processing grains (excepting soybean) were calculated by multiplying the production value by the percentage of crop use for food and then dividing it by the production value of all grains in 2020.

[b] Supply share of soybean for food is the same as the share of soybean usage for food in Table 7.

[c] USDA Economic Research Service, Feed Grains Yearbook. (https://www.ers.usda.gov/data-products/feed-grains-database/feed-grains-yearbook-tables/ of all)

In Table 2.8, the total cost of meat commodities consists of the cost share of feed grains and the cost share of other animal inputs (SA_k^m). The cost share of feed grains for meat products is calculated using the value of production for feed grains, the use of grains for feed (Table 2.6), and the supply share of crops for animal feeding (Table 2.7). Using these calculated cost shares of feed grains for meat products, the supply share of other animal inputs for meat products can be calculated as shown in Table 2.8.

Table 2.8. Cost-share of meat products (2020)

	Feed Grains[a]							Animal Inputs[b]				
	Soybean	Corn	Wheat	Rice	Barley	Oats	Sorghum	Cattle	Pork	Dairy	Poultry	Egg
Cattle	0.007	0.138	0.002	0.001	0.001	0.001	0.002	0.848	-	-	-	-
Pork	0.022	0.422	0.007	0.002	0.002	0.002	0.007	-	0.536	-	-	-
Dairy	0.003	0.064	0.001	0.000	0.000	0.000	0.001	-	-	0.930	-	-
Poultry & eggs	0.015	0.294	0.005	0.002	0.001	0.001	0.005	-	-	-	0.512	0.165

[a] The supply share of feed gains for meat products is calculated using the value of production, the share of crop usage for feed, and the supply share of feed for each animal product.

[b] The supply share of animal inputs for meat products is calculated as the share of the value that subtracts the supply share of feed grains from the production value of meat products.

Elasticities of Substitution

Elasticities of substitution are required to parametrize the commodity production nests. Few sources report elasticities of substitution for the agricultural commodities included in this study. The elasticity of substitution between aggregate agricultural commodities and marketing inputs (σ) is calculated as the weighted average of elasticities of substitution for six commodities (beef, pork, poultry, eggs, dairy, and fresh vegetables) reported by Wohlgenant (1989) (Figure 2.3). The weights are the variances calculated using the t-values reported in Wohlgenant's study (Table 2.9) which gives an approximation of the spread among the data points.

Table 2.9. Elasticities of substitution (SE) between agricultural commodities and marketing inputs

Commodity	The elasticity of Substitution (σ)	Variance
Beef and veal	0.45	0.45
Pork	0.01	0.02
Poultry	0.26	0.52
Eggs	0.08	0.16
Dairy	0.26	0.52
Fresh vegetables	0.26	0.52

Source: Wohlgenant (1989).
Note: t-values for the null hypothesis that $\sigma = 0$.

Protein-rich crops may be a substitute for some animal proteins and vice versa. Although a few studies report substitution possibilities between animal and plant-based proteins (Day, 2013; Sabate and Soret, 2014; Ismail et al., 2020), there is no existing literature on the elasticity of substitution between crops and livestock as raw material inputs for protein products. There is limited substitution between these inputs because they are highly differentiated. Grains and livestock are nearly perfect complements and tend toward a Leontief input relationship. For this reason, this study assumes that the elasticity of substitution between livestock and grains (σ^{ag}) is relatively low (0.01).

Three elasticities of substitution for grains, feed grains, and grains for food processing (σ^{c}, σ^{f}, σ^{a}) are from the Global Trade Analysis Project 9 Data Base Documentation (GTAP, 2016). The elasticity of substitution between livestock (σ^{l}) is based on Suh and Moss (2017). The model using these elasticity values is called CES-1. The sensitivity of the CES-EDM to the elasticity of substitution assumptions is evaluated in two additional models, called CES-2 and CES-3. CES-2 and CES-3 doubled and tripled, respectively, the elasticity of substitution between agricultural commodities (Table 2.10).

Table 2.10. Elasticities of substitution (SE) for nested CES technology

SE[a]	CES-1	CES-2	CES-3	
σ	0.45	0.45	0.45	between farm products & marketing inputs
σ^{ag}	0.01	0.02	0.03	between grains and livestock
σ^{c}	0.26	0.52	0.78	between oil-crop and grains
σ^{l}	0.08	0.16	0.24	between cattle, pork, and poultry
σ^{f}	0.26	0.52	0.78	between food processing grains
σ^{a}	0.26	0.52	0.78	between animal feed grains

[a] σ is Calculated weighted average value based on Wohlgenant (1989).
σ^{ag} is author's assumption.
Elasticities of substitution for σ^{c}, σ^{f}, σ^{a} are based on GTAP 9 Data Base Documentation. (https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=5138)
Elasticities of substitution for σ^{l} is based on Suh and Moss (2017).

Retail Food Value and Farm Production

Data on the value of production of each retail food product and each input commodity are needed to estimate social welfare effects. Data on expenditures by retail food products are from the US Bureau of Economic Analysis (BEA) personal consumption expenditures in 2020 (BEA, 2020). In 2020, total personal consumption expenditure for food was $1,746 billion (Table 2.11). The value of production for agricultural commodities, excluding fish and marketing inputs, is from the USDA National Agricultural Statistics Service (USDA-NASS, 2020). The value of fish production is from the personal consumption expenditures for fish and seafood (BEA, 2020). The value of marketing inputs is calculated from the sum of gross margins for wholesale trade for groceries and gross margins for retail grocery stores from the US Census Bureau (U.S. Census Bureau, 2020). In 2020, the total value of production for agricultural commodities, except for marketing inputs, was $369,787 million. Corn had the largest production value of $64,314 million, followed by cattle at $45,824 million (Table 2.12).

Table 2.11. Consumption expenditure for retail food products (2020)

Category	Expenditure (million $)
Cereal & bakery	163,776
Meat	202,712
Egg	14,492
Dairy	83,456
Fruits & vegetables	134,796
Other food	272,310
Non-alcoholic beverage	108,223
Alcoholic beverage	166,912
FAFH[a]	599,043

Source: U.S. Bureau of Economic Analysis, Personal Consumption expenditures table 2.4.5U, 2020. (https://apps.bea.gov/iTable/index_nipa.cfm)

[a] Food-Away-From-Home.

Table 2.12. Production value of agricultural commodities (2020)

Commodity	Value of Production (million $)
Vegetables & melon	14,152
Fruits & tree nut	28,119
Sugar cane & sugar beet	42,272
Peanut	1,294
Fish[a]	18,274
Marketing[b]	308,995
Soybean	45,732
Corn	64,314
Wheat	9,389
Rice	3,314
Barley	788
Oats	196
Sorghum	1,768
Cattle	45,824
Pork	18,056
Dairy	40,748
Poultry	26,892
Eggs	8,656

Source: U.S. Department of Agriculture, National Agricultural Statistics Service. (https://www.nass.usda.gov/Data_and_Statistics/)

[a] The value of production for fish used the personal consumption expenditures for ‘fish and seafood’ from the U.S. Bureau of Economic Analysis (BEA) (https://apps.bea.gov/iTable/index_nipa.cfm).

[b] The value of production for marketing inputs is the sum of gross margins for ‘wholesale trade-grocery and related products’ and ‘retail firms-grocery stores.’ And detailed data are available from the U.S. Census Bureau (census.gov).

Results

CFAP payments affect producers and consumers because the agricultural market is linked with retail food markets (Table 2.13). In general, farmers increase the supply of agricultural products after they receive CFAP assistance, leading to downward pressure on the price of agricultural inputs used to make retail food products. Table 2.13 reports the percentage change in the supply and price of 24 agricultural commodities due to CFAP payments. Discussion of the results begins first with those obtained under Leontief technology, followed by the CES results.

Changes in Price and Quantity: Leontief Production Technology

The supply of all commodities, except for vegetable and melon, fruit and tree nuts, and grains for food processing, is expected to increase following CFAP assistance. The price of agricultural commodities declines (Table 2.13). As shown in Table 2.1, about 86% of the CFAP payments were paid to feed grains and livestock products. The decline in the price of feed grains and livestock products implies that consumers enjoy some relief following CFAP as retail prices fall due to lower input costs. The decline in prices is largest for oats (-35.32%), cattle (-18.89%), barley (-13.63%), and wheat (-12.17%), all of which account for a large proportion of CFAP payments relative to the total value of production. Changes in the supply of feed grains such as sorghum (13.14%), soybean (5.06%), wheat (4.88%), and oats (3.29%) are greater than other commodities. In the case of vegetables and melons, fruits and tree nuts, and grains used to make processed food for retail, the change in supply has a negative effect, but a relatively small increase of less than 0.05%. As demand decreases for related food products such as cereals and bakeries, fruits and vegetables, and alcoholic beverages, the supply of these goods remains unchanged or in some cases decreases despite CFAP payments for farmers.

Table 2.13. Supply and price change in the agricultural commodity market

	Quantity Change (%)				Price Change (%)			
Commodity	Leontief	CES-1	CES-2	CES-3	Leontief	CES-1	CES-2	CES-3
Vegetables & melon	-0.04	0.24	0.39	0.47	-5.22	-4.99	-4.87	-4.81
Fruits & tree nuts	-0.03	0.20	0.32	0.39	-2.04	-1.90	-1.83	-1.79
Sugarcane & sugar beet	0.73	0.58	0.50	0.45	0.63	0.47	0.39	0.34
Peanut	0.62	0.49	0.43	0.38	-3.57	-3.72	-3.80	-3.85
Fish	0.80	0.47	0.31	0.22	1.51	0.69	0.29	0.05
Marketing	0.00	-3.64	-2.96	-2.55	0.00	0.00	0.00	0.00
Oil crop	0.73	4.08	6.50	8.33	-1.83	-1.52	-1.31	-1.14
Grains	-0.03	2.89	5.12	6.95	-1.48	-1.26	-1.12	-1.01
Cattle	1.07	9.07	12.95	15.22	-18.89	-12.36	-9.17	-7.29
Pork	1.01	4.71	6.56	7.64	-9.44	-6.34	-4.75	-3.79
Dairy	1.20	3.48	4.55	5.16	-6.89	-4.41	-3.24	-2.56
Poultry	0.33	1.16	1.60	1.85	-2.80	-1.94	-1.48	-1.18
Soybean	5.06	5.96	6.59	7.07	-3.81	-3.17	-2.72	-2.38
Corn	2.60	4.15	5.04	5.63	-8.59	-7.34	-6.63	-6.15
Wheat	4.88	6.89	8.40	9.60	-12.17	-10.58	-9.39	-8.44
Rice	1.66	2.60	3.22	3.66	-1.65	-0.88	-0.38	-0.02
Barley	0.77	5.63	9.14	11.84	-13.63	-11.56	-10.06	-8.91
Oats	3.29	12.14	18.18	22.67	-35.32	-29.45	-25.44	-22.46
Sorghum	13.14	13.93	14.43	14.8	-9.39	-9.14	-8.97	-8.85
Cattle inputs	1.07	9.07	12.95	15.22	-20.75	-13.26	-9.64	-7.51
Pork inputs	1.01	4.71	6.56	7.64	-10.25	-5.53	-3.18	-1.80
Dairy inputs	1.20	3.48	4.55	5.16	-6.77	-4.19	-2.99	-2.29
Poultry inputs	0.33	1.16	1.60	1.85	-0.99	-0.27	0.11	0.33
Egg inputs	0.33	1.16	1.60	1.85	-0.84	-0.05	0.37	0.62

Note: $\sigma = 0.45$ for all CES models.

For CES-1, $\sigma^{ag} = 0.01,\ \sigma^{c}, \sigma^{f}, \sigma^{a} = 0.26, \sigma^{l} = 0.08$.

For CES-2, $\sigma^{ag} = 0.02,\ \sigma^{c}, \sigma^{f}, \sigma^{a} = 0.52, \sigma^{l} = 0.16$.

For CES-3, $\sigma^{ag} = 0.03,\ \sigma^{c}, \sigma^{f}, \sigma^{a} = 0.78, \sigma^{l} = 0.24$.

A decrease in agricultural prices for food production leads to lower prices in retail food sectors. Changes in retail food demand caused by falling retail food prices depend on the own-price elasticity of demand and cross-price demand relationships, in addition to the magnitude of each food category's price decline. For the agricultural commodity market, the largest price change in the retail food market is for meat (−4.45%), while the smallest change in prices is for non-alcoholic beverages (−0.07%) and alcoholic beverages (−0.08%). Dairy products (1.67%) exhibit the largest increase in retail food demand due to falling prices, followed by meat (1.35%) and other foods (0.92%). Demand for cereals and bakeries, fruits and vegetables, alcoholic beverages, and FAFH decreases despite falling prices. This occurs is because the substitution effect is greater than the income effect due to price change when the prices of other products also fall. For example, when the cereal price decreases, consumers may increase other food consumption rather than increase cereal purchases (Table 2.14).

Table 2.14. Demand and price change in the retail food market

	Quantity Change (%)				Price Change (%)			
Commodity	Leontief	CES-1	CES-2	CES-3	Leontief	CES-1	CES-2	CES-3
Cereal and bakery	-0.65	-0.52	-0.45	-0.41	-0.11	-0.10	-0.08	-0.08
Meat	1.35	0.82	0.55	0.40	-4.45	-2.95	-2.21	-1.77
Eggs	-3.33	-1.85	-1.15	-0.75	-1.92	-1.33	-1.01	-0.81
Dairy	1.67	1.08	0.80	0.65	-1.90	-1.21	-0.89	-0.71
Fruits and vegetables	-0.15	0.21	0.39	0.50	-1.84	-1.75	-1.71	-1.68
Other foods	0.92	0.73	0.62	0.56	-0.40	-0.36	-0.33	-0.31
Non-alcoholic beverages	0.33	0.16	0.08	0.03	-0.07	-0.07	-0.07	-0.07
Alcoholic beverages	-1.08	-0.69	-0.50	-0.39	-0.08	-0.07	-0.07	-0.06
FAFH[a]	-0.39	-0.29	-0.24	-0.21	-0.32	-0.22	-0.17	-0.14

Note: $\sigma = 0.45$ for all CES models.

For CES-1, $\sigma^{ag} = 0.01,\ \sigma^{c}, \sigma^{f}, \sigma^{a} = 0.26, \sigma^{l} = 0.08$.

For CES-2, $\sigma^{ag} = 0.02,\ \sigma^{c}, \sigma^{f}, \sigma^{a} = 0.52, \sigma^{l} = 0.16$.

For CES-3, $\sigma^{ag} = 0.03,\ \sigma^{c}, \sigma^{f}, \sigma^{a} = 0.78, \sigma^{l} = 0.24$.

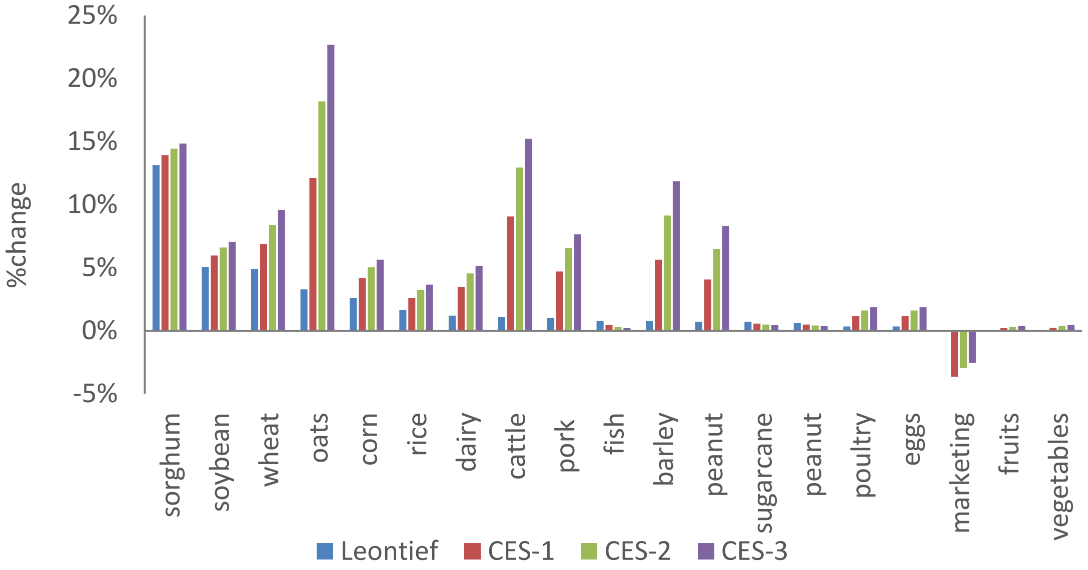
[a] Food-Away-From-Home.

Changes in Price and Quantity: CES Production Technology

Figure 2.4 shows the changes in supply and price for agricultural commodities estimated under the assumption of Leontief and CES production technology. Results suggest that as substitutability between inputs increases, the change in the supply of agricultural commodities increases but changes in price change decrease. When substitution between agricultural commodities is possible, producers are able to maximize profits by increasing low-cost input instead of other inputs. This results in a reduction in the total cost of producing food. As a result, the magnitude of the price change is moderated across all agricultural commodities. For example, and considering the EDM with Leontief production functions only, the supply of cattle increased by 1.07%, but when substitution between grains and livestock, and between livestock including cattle, pork, dairy, and poultry is possible, the supply of cattle increased from 0.97% (CES-1) to 15.22% (CES-3), depending on the magnitude of their elasticity of substitution (Table 2.13). The decline in the price of cattle is moderated from 18.89% (CES-1) to 7.29% (CES-3) due to an increase in demand for food processing. Similarly, for the EDM with only Leontief production technology, the supply of oats increased by 3.29% and the price decreased by 29.45%. CES technology produces different results. For example, the supply of oats increased from 12.14% (CES-1) to 22.67% (CES-3), and the price decline changed from 29.45% (CES-1) to 22.46% (CES-3) as the elasticity of substitution increased.

Figure 2.5 shows the changes in demand and prices for retail food products under the different production technology assumptions for agricultural commodities. When substitution between inputs is possible, food manufacturers reorient their input mix toward relatively cheaper bundles, which results in downward pressure on agricultural and food prices. The change in the mix of inputs, increasing inputs, which have a large drop in prices, has an effect mitigating the decline in prices of aggregate retail food as well as aggregate agricultural products. The results suggest that the economic benefits of CFAP payments to farmers increase due to the possibility of substitution between agricultural commodities in food product processing. For example, for the EDM with Leontief technology only, the price of meat decreased by 4.45% but demand for meat increased by 1.35%. Increasing the elasticity of substitution between composite crops and livestock, and between livestock, the demand for meat increased from 0.40% (CES-3) to 0.82% (CES-1), and the price declined from 2.95% (CES-1) to 1.77% (CES-3) (Table 2.13).

Supply change



Price change

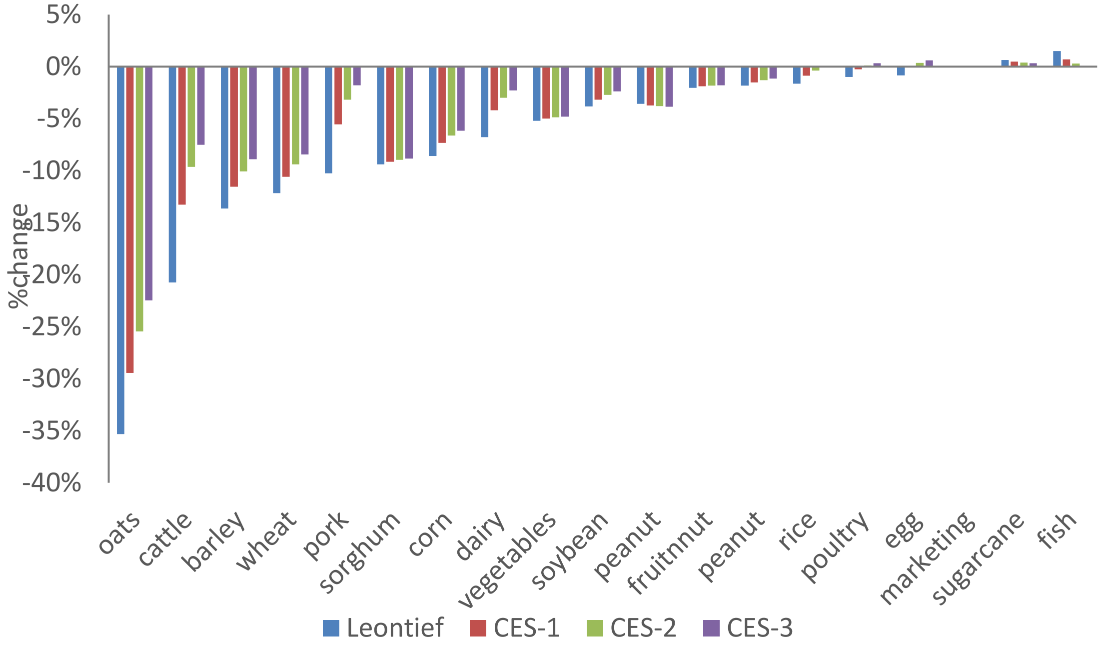


Figure 2.4. Supply and price change in the agricultural commodity market

Note: $\sigma = 0.45$ for all CES models.
For CES-1, $\sigma^{ag} = 0.01$, $\sigma^c, \sigma^f, \sigma^a = 0.26, \sigma^l = 0.08$.
For CES-2, $\sigma^{ag} = 0.02$, $\sigma^c, \sigma^f, \sigma^a = 0.52, \sigma^l = 0.16$.
For CES-3, $\sigma^{ag} = 0.03$, $\sigma^c, \sigma^f, \sigma^a = 0.78, \sigma^l = 0.24$.

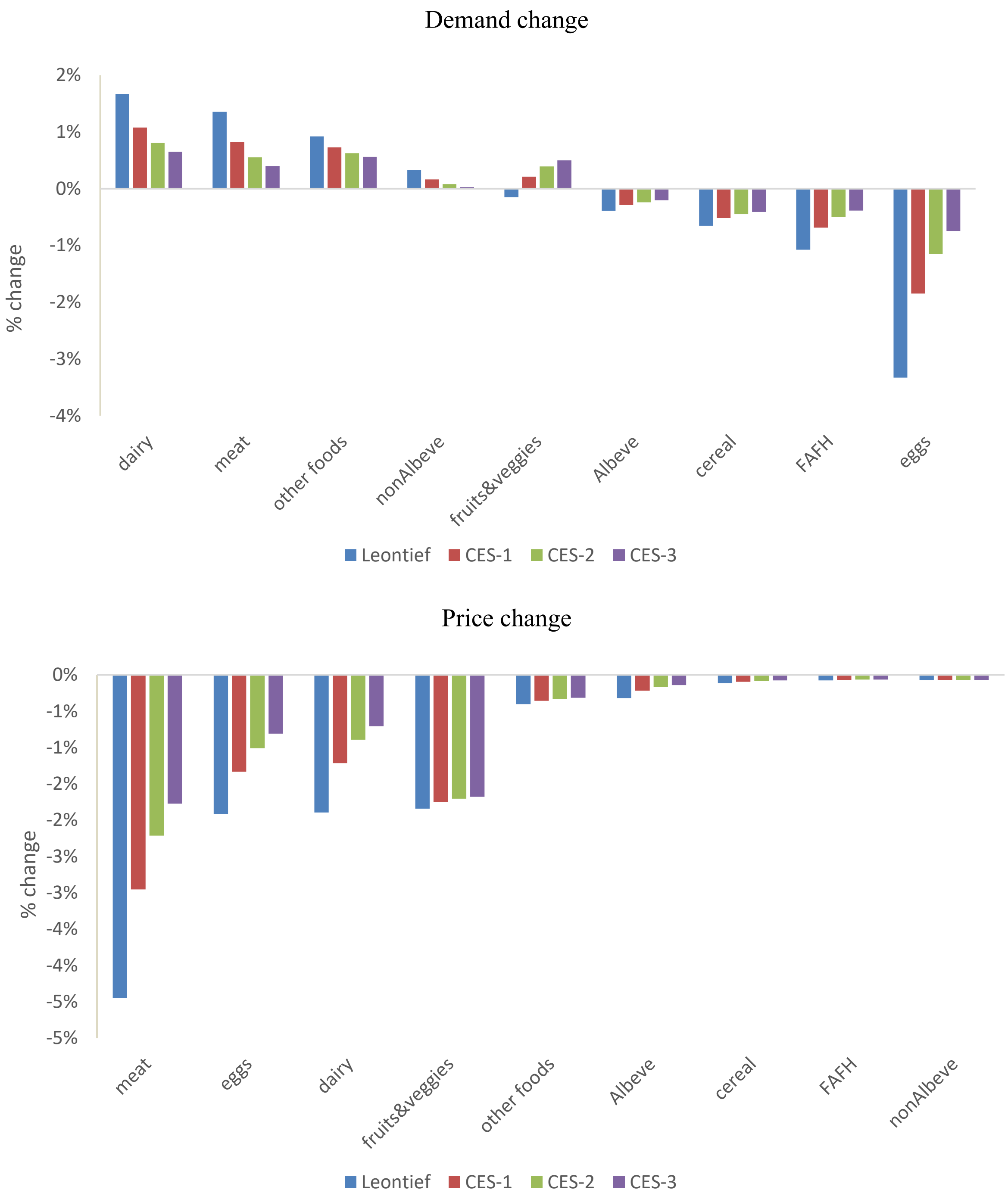


Figure 2.5. Demand and price change in the retail food market

Note: $\sigma = 0.45$ for all CES models.
For CES-1, $\sigma^{ag} = 0.01$, $\sigma^{c}, \sigma^{f}, \sigma^{a} = 0.26, \sigma^{l} = 0.08$.
For CES-2, $\sigma^{ag} = 0.02$, $\sigma^{c}, \sigma^{f}, \sigma^{a} = 0.52, \sigma^{l} = 0.16$.
For CES-3, $\sigma^{ag} = 0.03$, $\sigma^{c}, \sigma^{f}, \sigma^{a} = 0.78, \sigma^{l} = 0.24$.

Welfare Effects

Regarding changes in welfare, the results suggest that all segments of the food industry benefitted from CFAP assistance. The objective of CFAP was to support farmers as prices collapsed during the COVID-19 outbreak. Therefore, changes in social welfare corresponding with this intervention are calculated using the quantity and price changes estimated by the model and the value of production data reported in 2020. Table 2.15 reports the aggregate effects of CFAP payments in the US food industry.

Table 2.15. Aggregate effects of CFAP payments

	Model Assumption			
Changes in Surplus (million $)	Leontief	CES-1	CES-2	CES-3
Domestic food consumers	16,809	12,212	9,934	8,570
Domestic agricultural producers	5,357	11,312	14,493	16,501
Foreign consumers	2,725	2,309	2,039	1,842
Ethanol market related	1,885	1,609	1,454	1,348
Taxpayers	-26,773	-26,773	-26,773	-26,773
Total welfare	3	670	1,146	1,488

Note: $\sigma = 0.45$ for all CES models.
For CES-1, $\sigma^{ag} = 0.01,\ \sigma^{c}, \sigma^{f}, \sigma^{a} = 0.26, \sigma^{l} = 0.08$.
For CES-2, $\sigma^{ag} = 0.02,\ \sigma^{c}, \sigma^{f}, \sigma^{a} = 0.52, \sigma^{l} = 0.16$.
For CES-3, $\sigma^{ag} = 0.03,\ \sigma^{c}, \sigma^{f}, \sigma^{a} = 0.78, \sigma^{l} = 0.24$.

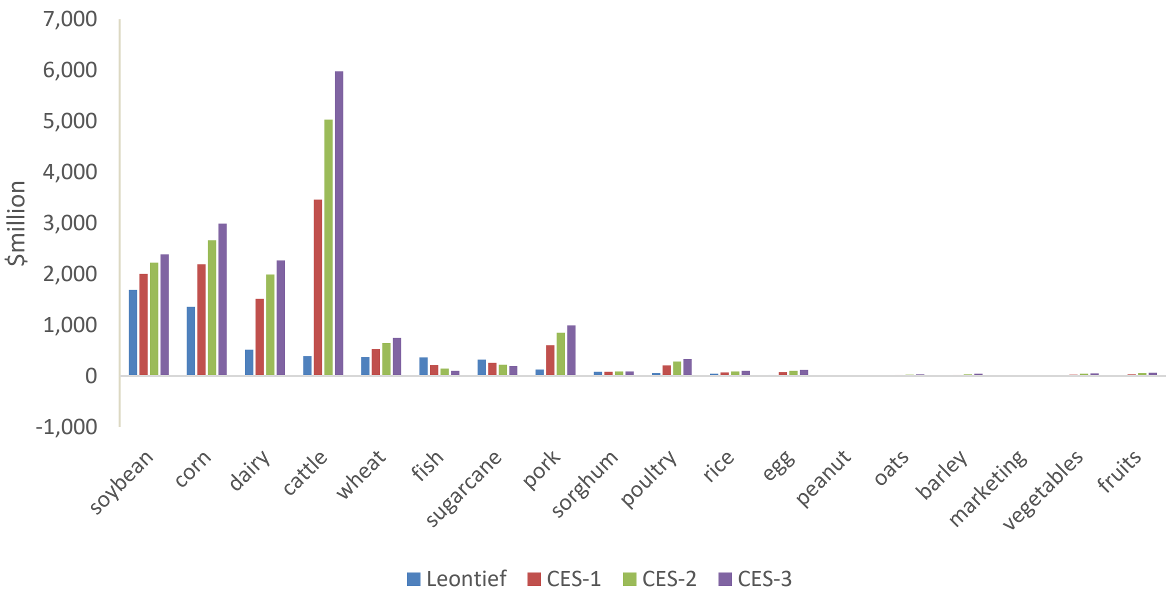
Under the assumption of Leontief production technology, domestic food consumers are better off by $16.8 billion. This happens because CFAP support led to a decline in the price of all retail foods, from a high of about 4.45% for meat to a low of about 0.07% for non-alcoholic beverages. Foreign buyers of US agricultural products and buyers of corn for ethanol production both gain about $2.7 billion and $1.9 billion in surplus, respectively, because commodity prices are moderated following CFAP implementation. These findings suggest that CFAP payments to farmers are associated with a 2.6% decline in corn prices. In aggregate, agricultural producers gain about $5.4

billion. Although most commodity prices decline, the financial support from CFAP, along with the increase in demand quantity for farm products, results in a net benefit for agricultural producers.

Taxpayers bear the cost of CFAP. Taxpayers lose about $26.7 billion by spending the government budget to support farmers. As Table 2.15 shows, the aggregate gain to the consumers and producers more than offsets the losses to the taxpayers. The total change in social welfare of CFAP payments is $3 million. The impacts of CFAP payment on the US food industry are more diffuse on the individual retail food and commodity prices. The magnitude of the impacts for an individual food or agricultural commodity depends on the assumption of production technology in the agricultural market.

Figure 2.6 shows the economic impacts of CFAP payments on the agricultural and retail food markets under different production technology functions. When substitution is possible between the agricultural commodities as input for food production, the economic benefits following CFAP are transit from consumers to producers, increasing the economic surplus of producers. On the other hand, as increase the elasticity of substitution between substitutable commodities, the economic surplus of producers of agricultural commodities such as vegetables and melon, fruits and tree nuts, sugarcane and sugar beet, peanut, and fish decreases. Figure 2.7 shows the aggregate surplus effects of CFAP payments on all consumers and producers under different assumptions of substitutability. As elasticities of substitution increase, consumer surplus is transferred to producers. In addition, the reduction in the total costs of agricultural commodities for food processing induced those results from input substitution increases the value of the total social welfare. Consumer surplus decreases from $16.8 billion (Leontief) to $8.5 billion (CES-3), while producer surplus rises from $5.3 billion (Leontief) to $16.5 billion (CES-3) depending on the substitutability (Table 2.15). The surplus for foreign buyers of US grains and buyers of corn for ethanol production decreases somewhat as the substitutability increases, but not much difference between the models.

Agricultural market



Retail food market

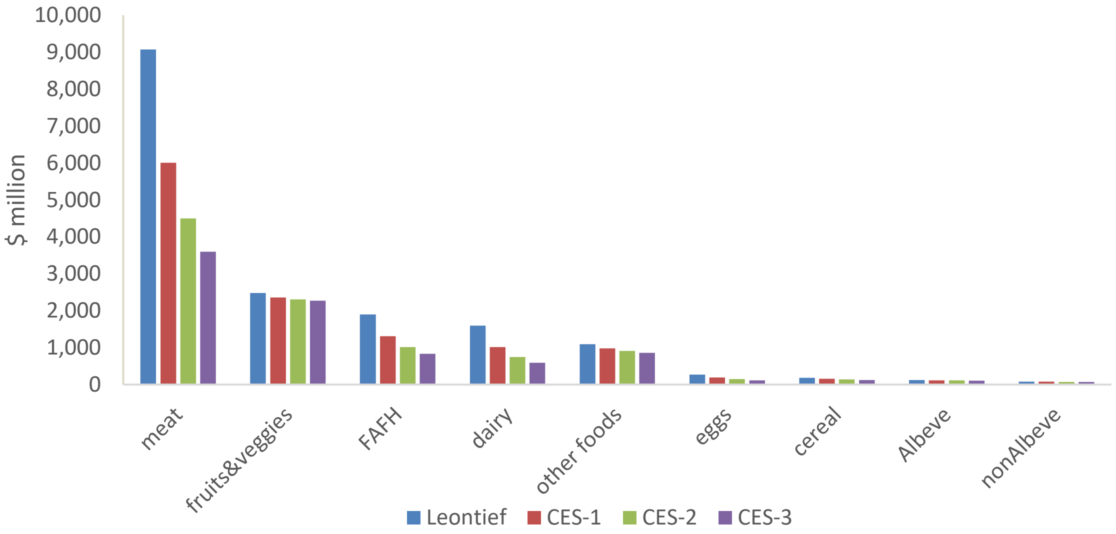


Figure 2.6. Surplus effects of CFAP in the agricultural and retail food markets

Note: $\sigma = 0.45$ for all CES models.

For CES-1, $\sigma^{ag} = 0.01$, $\sigma^c, \sigma^f, \sigma^a = 0.26, \sigma^l = 0.08$.

For CES-2, $\sigma^{ag} = 0.02$, $\sigma^c, \sigma^f, \sigma^a = 0.52, \sigma^l = 0.16$.

For CES-3, $\sigma^{ag} = 0.03$, $\sigma^c, \sigma^f, \sigma^a = 0.78, \sigma^l = 0.24$.

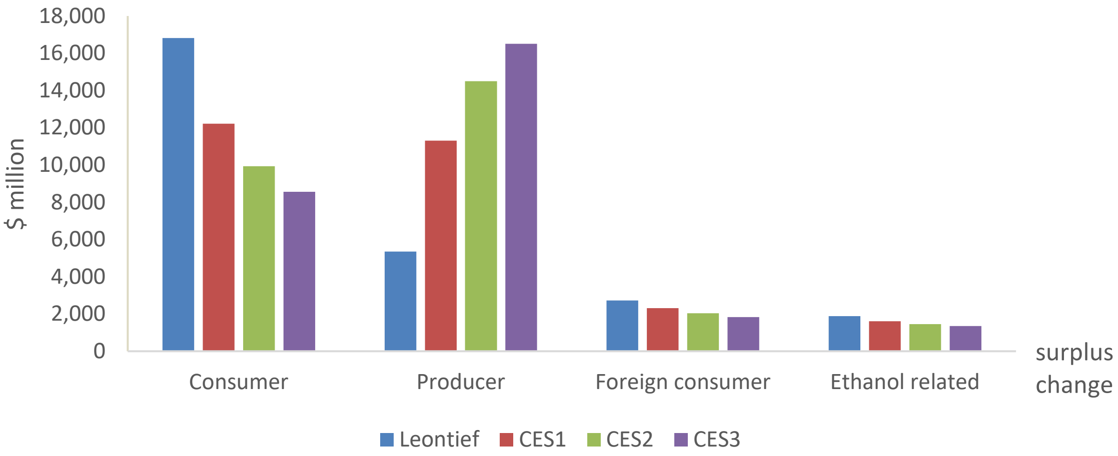


Figure 2.7. Aggregate surplus effects of CFAP payments

Note: $\sigma = 0.45$ for all CES models.
For CES-1, $\sigma^{ag} = 0.01$, $\sigma^{c}, \sigma^{f}, \sigma^{a} = 0.26, \sigma^{l} = 0.08$.
For CES-2, $\sigma^{ag} = 0.02$, $\sigma^{c}, \sigma^{f}, \sigma^{a} = 0.52, \sigma^{l} = 0.16$.
For CES-3, $\sigma^{ag} = 0.03$, $\sigma^{c}, \sigma^{f}, \sigma^{a} = 0.78, \sigma^{l} = 0.24$.

Conclusions

This study addressed the limitation of the fixed proportion technology assumption typically used in EDM by introducing nested CES technologies as production functions. The nested CES structure consists of multiple sub-sectors of the farm commodity market. The empirical example estimated the magnitude of the effects of the CFAP payments in the US food industry. Using a model that links the production of 24 agricultural products with nine retail food categories, the effects of the financial assistance to producers and consumers in the US food industry were demonstrated. The implementation of assistance payments for farmers whose product prices have fallen due to COVID-19 is estimated to generate $26,776 million in benefits under the assumption of a fixed proportion production function. Total societal benefits are estimated at $3 million comparing the actual expenditure of the government to the benefits of payments. Payments paid to farmers not only benefit farmers, but also food consumers via lower food prices. When agricultural products cannot be substituted, more benefits of agricultural price support accrue to consumers rather than producers.

If agricultural inputs for food production can be substituted, producers are able to maximize benefits by increasing the supply of commodities that are favorable to a low-cost input mix. As a result, as changes in the supply of agricultural commodities affect food prices, consumer benefits are transferred to producers, and producer's benefits increase. The greater the substitutability between agricultural commodities, the more producers benefit from CFAP payments than consumers. Therefore, the flexibility of the agricultural market that can be substituted between commodities allows assistance paid to producers to be more attributed to producers' benefits and improves the overall social welfare by increasing the benefits of producers.

The government's immediate financial support for price decline in the first half of 2020 would have directly affected producers' decisions to supply agricultural products in the second half of that year, which is expected to have vertically shifted the supply curve. However, there are several limitations to this study. In EDM, expansionary displacements assume that there are no limitations on production capacity so some contractionary displacements can exceed 100 percent of the base level of the activity, which is infeasible in practice. That means, the displacements cannot be guaranteed to be on the efficient frontier of the underlying production functions (Harrington and Dubman. 2008). The model in this study did not consider the producer's capacity to adjust supply quantity and the time lag between application for payment and payment implementation of CFAP. In practice, producers cannot significantly change supply in the short term, but the study did not take into account short-term inelastic supply. Because EDM is a partial equilibrium model, it does not reflect the impact of other related sectors linked to the industry estimated. For example, the effects of macro-economic conditions such as exchange rate, and unemployment rates are excluded. Therefore, the incentive effect of CFAP payments estimated in this study may have been overestimated than they actually generated.

Another concern is that costs involved in implementing assistance programs were ignored in measuring social welfare changes. Considering the government's employee compensation and transaction costs incurred when managing the CFAP program, the total social welfare may have decreased rather than increased. Even considering the deadweight loss due to implementation costs, virtually all groups, including domestic food consumers, foreign crop buyers, and agricultural producers, benefits from the government’s payment. Therefore, there may be benefits for payments not included in the surplus measures, for example, the transfer of program funds to many people living in rural or rural communities. Therefore, the increase in consumer and producer surplus from program payments proves the effectiveness and validity of the program.

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CHAPTER III

AN EQUILIBRIUM REPLACEMENT MODEL FOR RECOVERING ECONOMIC SHOCKS TO THE U.S. FOOD INDUSTRY

Abstract

The study is the first attempt to quantify the sector-specific shocks driving inflationary trends in the US food industry using a parametric modeling approach. The magnitude and direction of the shocks leading to changes in the price and quantity of agricultural commodities and retail food products are recovered by reformulating the Lusk (2017) and Okrent and Alston (2012)'s (LOA) EDM structure as an Equilibrium Replacement Model (ERM). Recovered shocks suggest that the agricultural market has a mixed supply shock direction, and its range is large, while the retail food market has a close to positive demand shock direction and the range is less than that of the agricultural market. Social welfare changes caused by demand and supply shocks have steadily risen, except in 2008, 2011, and 2020, when the global financial crises occur. The estimated shocks can be used to determine the effects of changes in the macroeconomic variables. The ERM approach is parametric, depending solely on the demand and supply correspondence with elasticities and industry cost share so it has an advantage over empirical econometric modeling techniques relying on the model specification.

Introduction

The objective of this study is to quantify the sector-specific shocks driving inflationary trends in the United States (US)'s food industry. An equilibrium displacement model (EDM) is used to recover the magnitude and direction of the shocks, or external disruptions, causing price-quantity relationships to change. This approach differs from conventional EDM analyses. EDM is typically used to analyze the effects of exogenous shocks tied to changes in policy, weather events, or other external shocks on the direction and magnitude of price and quantity changes caused by shocks and concomitant changes in social welfare. Here, the EDM is used as a forensic tool to recuperate the disruptions leading to changes in prices and quantities. The procedure differs from empirical approaches, such as structural vector autoregression (VAR) or other econometric modeling techniques, for estimating what caused changes in price-quantity equilibrium. First, the suggested approach is parametric, depending solely on the EDM's demand and supply correspondences established with published elasticities and industry cost share data. Second, the procedure endogenizes shocks and uses proportional changes in prices and quantities as exogenous data to recover shocks. In this way, the EDM is reformulated and implemented as an 'Equilibrium Replacement Model' (ERM).

An empirical application of the ERM estimates the shocks driving trends in year-over-year price changes for agricultural products and retail food products. The US economy is experiencing record inflation rates not seen since 1982. The havoc COVID-19 wreaked on global supply chains, coupled with pent-up demand and the trillions of dollars injected into the economy through the American Rescue Plan, are commonly cited as proximate causes for the inflation observed today. The year-over-year core rate of inflation has increased to 8.3 percent, while the price of poultry has increased by more than 15 percent, followed closely by beef, pork, and grains. Energy prices have increased, with the cost of gas at the pump 43% higher than it was in 2021 (BLS, 2022). Market uncertainty caused by Russia's war against Ukraine has further exacerbated inflationary trends, causing increases in petroleum, fertilizer, and commodity prices. These macro events are postulated as price inflation drivers.

Lusk (2017) and Alston and Okrent (2012)'s EDM is used in the analysis. Shocks estimated by this model are subsequently regressed on macro-economic variables, including per capita gross domestic product (GDP) and energy price index (EPI). The objective of the regression is to determine the *ceteris paribus* effects of changes in the macro variables on the US food industry prices and quantities, inter alia shocks, and measure changes in attendant social welfare.

Literature Review

Equilibrium Displacement Models (EDM) are frequently used to evaluate exogenous shocks such as government policies, generic advertising, or increased demand on markets and the resulting changes in aggregate social welfare (Muth, 1964; Wohlgenant, 1989; Balagtas and Kim, 2007; Lusk and Anderson 2004; Okrent and Alston 2012; Lusk, 2017). Okrent and Alston (2012) developed a multi-sector EDM linking agricultural commodity and retail food markets to analyze the effect of food policies for obesity on food demand, body weight, and social welfare. Lusk (2017) extended Okrent and Alston (2012)'s EDM to analyze the distributional effects of crop insurance subsidies. While the structure of EDM has been conventionally used to capture changes in price and quantity due to exogenous shocks, in this study, the structure of equations is used to recover the magnitude and direction of the exogenous shocks, or external disruptions leading to changes in price and quantities.

Many studies have been conducted using empirical approaches, such as vector autoregression or other econometric modeling techniques to determine what drives change in market equilibrium conditions. Baek and Koo (2010) used cointegration procedures to investigate the dynamic relationship between the US farm income and macro-economic variables such as the exchange rate, agricultural prices, the domestic income, and the interest rate. Lambert and Gong (2010) used a dynamic cost function model to determine the farm's response to changes in energy prices. Saghaian (2010)'s contemporary time-series analysis and Granger causality tests to reveal that oil and crop commodity prices are strongly correlated but the evidence for a causal link is mixed. Hanon (2014) examined the impact of the Renewable Fuel Standard (FRS) mandates on corn prices and global food prices using economic models for estimating the price. However, it has been criticized that econometric modeling techniques are inevitably the subject of specification search problems. Lucas (1976) argued that economic policy evaluation using econometric models based on relationships observed from aggregated historical data is incomplete because does not include rational expectations. Freedman (2005) and Syll (2018) were skeptical of the difficulty of verifying many of the assumptions made in regression studies and the effect that false assumptions can have on the validity of conclusions. Fernandez-Villaverde and Rubio-Ramirez (2008) also mentioned a sensitivity of model specification of structural vector autoregressions as well as the problem of not reflecting other mechanisms such as market expectations inherent in future prices, the possibility of omitted correlated variables. According to Ghanem and Smith (2021), the system approach can estimate a complete causal linkage between the variables but doing so necessitates making some strong model specification assumptions.

The structure of EDM offers a parametric procedure for recovering shocks that drive changes in price-quantity equilibrium. The procedure used here applies the EDM in reverse. In other words, rather than introducing external shocks to disrupt equilibrium, observed proportionate changes in prices and quantities are introduced into the EDM which then solves for the corresponding shocks that gave rise to the observed prices and quantities. The ERM approach approximates policy-inducing changes in social welfare based on the general framework for market equilibrium that does not depend on the specific choices in functional forms of consumer spending or producer profitability. The model uses published elasticity and cost-share data and estimates the shocks from the structural equations. Estimating shocks for a specific year does not require historical data and does not follow specific model specifications and assumptions, so it has an advantage over conventional econometric modeling techniques.

Recently, some studies have been conducted to evaluate the impact of COVID-19. Ridley and Devadoss (2021) estimated the effects of COVID-19 on fruit and vegetable production in the farm labor force using a county- and commodity-level production function and the supply elasticity of labor. Lusk (2021) described wholesale meat and livestock price dynamics during the COVID-19 disruption and showed how supply shocks affect marketing margins. Malone, Schaefer, and Lusk (2020) investigated how the shift from ‘food away from home’ and towards household consumption affect the egg industry using econometric modeling. These studies demonstrate the impact of COVID-19 on specific commodity markets, but it is not sufficient to explain the price and quantity changes caused by the recent inflation trends in the US food industry. ERM approach linking agriculture to the retail food market allows for analysis of the distributional effects of inflationary trends that reflect social issues such as COVID-19 disruption on the US food industry. Previous studies on inflation have mainly predicted or described inflation from a macroeconomic perspective, but there has been a lack of attention on the impact of inflationary trends on the industry in a view of microeconomic perspective (Bruno and Easterly, 1998; Stock and Watson, 1999; Stock and Watson, 2007; Cogley and Sbordone, 2008; Stock and Watson, 2010; Faust and Wright, 2013). The contribution of this study is that it develops a methodology for estimating the effects of inflation leading to price and quantity changes in the US food industry.

Methods and Procedures

Lusk (2017)’s equilibrium displacement model (EDM) is used to estimate economic shocks caused by price inflation resulting from Covid-19 supply chain bottlenecks, the Federal Reserve’s fiscal policies implemented during Covid-19, and Russia’s war with Ukraine. The focus is on current inflationary trends observed in the food industry. The EDM is re-cast in what may be called an ‘Equilibrium Replacement Model’ (ERM). The ERM differs from the EDM in an important way. EDM’s predict the new quantity and price equilibrium, given an exogenous shock introduced by the researcher. The ERM works in reverse (Figure 3.1). The ERM estimates the direction and magnitude of shocks leading to observed equilibrium prices and quantities. In this way, the ERM recovers the magnitude and direction of shocks that drove observed changes in prices and quantity. The question posed here is, what are the sizes and signs of the shocks that are consistent with the inflationary pressures on food prices observed in 2022.

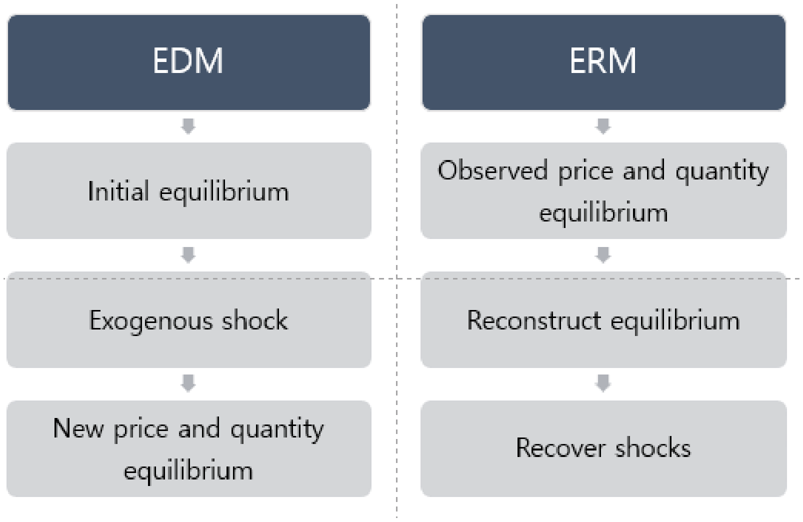

Figure 3.1. The procedure of EDM and ERM

Three ERM models are developed here. The baseline model (BASELINE) observes year-over-year proportionate changes in the price and quantity of both retail food products and agricultural commodities to recover parent shocks, which are now determined endogenously. The baseline model is the most restricted model that uses changes in farm supply quantities as observed values.

Models 2 and 3 assume that 1) farm and retail production technologies are known, and 2) changes in farm supply are determined endogenously. Model 2 assumes that farm commodities are produced with Leontief technology. Model 3 allows for substitution between productive factors for the retail sector, and therefore assumes that this sector's production technology is a CES production function for retail food production. The baseline model estimates shocks using Lusk (2017)'s EDM structure. The ERM consists of final demands for nine retail foods[4], and input supplies of 24 farm

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[4] (1) cereal and bakery, (2) meat, (3) eggs, (4) dairy, (5) fruit and vegetable, (6) other foods, (7) non-alcoholic beverages, (8) alcoholic beverages, and (9) food away from home (FAFH). The numbers in parentheses before the detailed list of retail goods indicate the subscripts in the equations.

products[5]. Figure 2.2, Chapter 2 summarizes Lusk (2017)'s EDM and its linkages between farm commodity production and final food consumption.

There are nine retail demand equations in log-differential form:

$(1) - (9)\ \hat{q}_i = \sum_{j=1}^{9} \eta_{ij} \cdot \hat{p}_j + \eta_{ii} \cdot \delta_i \quad \text{for } i = 1 \text{ to } 9$

where $\hat{q}_i$ is the proportionate change in the quantity of retail good i consumed, $\hat{p}_i$ is the proportionate change in the retail price of good i, η_{ij} is the demand elasticity of good i with respect to the price of good j, and η_{ii} is the own-price elasticity for good i. The demand-shock for the retail good i, δ_i, is the proportionate change in consumer willingness to pay. In contrast to an EDM, $\hat{q}_i$ and $\hat{p}_i$ are observed values and δ_i is a free variable that explains the cause behind the observed equilibrium.

Changes in the supply of agricultural commodities are:

$(10) - (27)\ \ \frac{\Delta X}{X} = \hat{x}_k = \varepsilon_k \cdot (\widehat{w}_k + \varphi_k) \qquad \text{for } k = \ 7\ to\ 24$

where $\hat{x}_k$ is the proportionate change in the supply of agricultural commodity k, $\widehat{w}_k$ is the proportionate change in the price of input commodity k, ε_k is the own-price elasticity of supply for commodity k, and φ_k is an economic shock in supply.

Changes in demand for feed grains are determined by the share of the crop used to produce food (F), exports (T), animal feed (A), and ethanol (E) as follows:

$(28 - 34)\ \hat{x}_k = S_k^F \cdot \hat{x}_k^F + S_k^T \cdot \hat{x}_k^T + S_k^A \cdot \hat{x}_k^A + S_k^E \cdot \hat{x}_k^E \qquad \text{for } k = 13 \text{ to } 19$

where $S_k^F, S_k^T, S_k^A, S_k^E$ are the supply share of feed grains used in food, export, animal feed, and ethanol production, respectively.

Change in oil crop demand ($\hat{x}_1$) for food processing and its price ($\widehat{w}_1$) are calculated using the shares of soybean used for food and the cost share of soybean (S_1) in the total cost of producing oil crops as:

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[5] (1) oil crops, (2) grains, (3) cattle, (4) pork, (5) dairy, (6) poultry and egg, (7) vegetables and melon, (8) fruits and tree nuts, (9) sugar cane and sugar beet, (10) peanut, (11)fish, (12)marketing inputs, (13) soybeans, (14) corn, (15) wheat, (16) rice, (17) barley, (18) oats, (19) sorghum, (20) cattle inputs, (21) pork inputs, (22) dairy inputs, (23) poultry inputs, and (24) egg inputs The numbers in parentheses before the detailed list of agricultural commodities indicate the subscripts in the equations.

$(35)\ \hat{x}^F_{13} = \hat{x}_1$

$(36)\ \widehat{w}_1 = S_1 \cdot \widehat{w}_{13}$

Change in grain demand for food processing ($\hat{x}_2$) derived from feed grains such as corn, wheat, rice, barley, oats, and sorghum is the change in feed grain usage for food (S^F_k). The price change ($\widehat{w}_2$) is calculated using the cost-share ($S_{2,k}$) of each feed grain in the total cost of producing grains for food processing. These relations are:

$(37-42)\ \hat{x}_2 = \hat{x}^F_k$ for $k = 14$ to 19

$(43)\ \widehat{w}_2 = \sum_{k=14}^{19} S_{2,k} \cdot \widehat{w}_k$

For livestock commodities, the change in the quantity of livestock commodities demanded is determined by the quantity share of the total production of animal input k used by livestock commodity m (SM^m_k):

$(44-48)\ \hat{x}_k = \sum_{m=3}^{6} SM^m_k \cdot \hat{x}_m$ for $k = 20$ to 24

Changes in the price of livestock commodities ($\widehat{w}_k, k = 3$ to 6) are calculated using the cost shares of the total production of livestock commodity m contributed by animal-feeding grain, k (SA^m_k).

$(49-52)\ \widehat{w}_k = \sum_{m=13}^{24} SA^m_k \cdot \widehat{w}_m$ for $k = 3\ to\ 6$

The baseline model for recovering ex-post economic shocks consists of 47 vectors of endogenous variables and a 52 × 52 matrix of elasticity and cost-share parameters. The observed changes in price and quantity in the retail food market ($\hat{p}_j$ and $\hat{q}_j$) and farm commodity market ($\widehat{w}_k$and $\hat{x}_k$) from 1993 to 2021 are used to estimate the shocks corresponding with period-to-period changes.

Leontief Production Technology

To investigate the relationship between the substitutability of agricultural input commodities for food production and the determination of shocks, the ERM production technology is extended to include Leontief or nested CES technologies. Model 2, which assumes the Leontief production function, uses the observed changes in price and quantity ($\hat{p}_j$ and $\hat{q}_j$) in the retail food market and changes in price ($\widehat{w}_k$) in the agricultural commodity market as fixed parameters, but changes in the supply of agricultural commodity ($\hat{x}_k$) are determined endogenously in the ERM specification. To derive changes in the supply of agricultural commodities in Model 2, the following equations (Equation 53 – 79) are added in addition to the baseline model equations.

Changes in the demand for farm commodities, which are directly involved in the production of retail food foods, are estimated with the sum-product of the cost-share of commodity k used by retail product i and changes in the output:

$(53-64)\ \hat{x}_k = \sum_{i=1}^{9} SC_k^i \cdot \hat{q}_i \qquad$ for $k = 1$ to 12, with $\sum_{i=1}^{9} SC_k^i$=1

Using the supply shares of crops used for food, export, animal feed, and ethanol production, changes in the total demand for feed grains ($\hat{x}_k,$ for k 13 to 19) are calculated by Equations $(28-34)$. In Model 2, changes in the demand for feed grains for each purpose are not fixed parameters but are estimated in the model structure. Change in demand for soybean used to produce food ($\hat{x}_{13}^F$) is estimated using Equation (35) and Equation (53). Changes in the demand for feed grains (except for soybean) for food ($\hat{x}_k^F$, k=14 to 19) are estimated using Equation $(37-42)$ and Equation (54). Changes in the demand for feed grains (including soybean) for export ($\hat{x}_k^T$), animal feed ($\hat{x}_k^A$), and ethanol ($\hat{x}_k^E$) are:

$(65-71)\ \hat{x}_k^T = \eta_{k,T} \cdot \widehat{w}_k \qquad$ for $k = 13$ to 19

$(72-78)\ \hat{x}_k^A = \sum_{m=3}^{6} SM_k^m \cdot \hat{x}_m \qquad$ for $k = 13$ to 19

$(79)\ \hat{x}_{14}^E = \eta_{14,E} \widehat{w}_{14}$

with $\eta_{k,T}$ the own-price elasticity of export demand for the k^{th} feed grain and $\eta_{k,T}$ the own-price demand elasticity of corn by ethanol producers. Changes in the demand for animal inputs ($\hat{x}_k$ for $k =$ 20 to 24) are also not fixed parameters but estimated using the interaction between Equation $(44-48)$ and Equation $(55-58)$. Model 2 for recovering ex-post economic shocks consists of 79 vectors of endogenous variables and 79 × 79 matrices of model parameters by adding 27 vectors of endogenous variables to the baseline model.

Nested CES Production Technology

Model 3 allows for substitutability between (1) farm commodities and marketing inputs, (2) grains and livestock outputs, (3) oil crops and grains, and (4) livestock outputs. Model 3 assumes there is no substitution between vegetables and melons, fruits and tree nuts, sugar cane and sugar beets, peanuts, and fish. Similarly, animal inputs for cattle, pork, dairy, poultry, and eggs are not substitutes. In Chapter 2, Figure 2.3 shows the nested CES production and agricultural commodity market for Model 3.

For non-substitutable commodities, such as (7) vegetables and melons, (8) fruits and tree nuts, (9) sugar cane and sugar beet, (10) peanuts, and (11) fish, changes in the supply of these commodities are determined by the sum-product of the cost shares of commodity k used by retail's production of food good i and the changes in output. Equations $(59 - 63)$ are used to estimate changes in the supply of non-substitution and that are directly engaged in final retail food production ($\hat{x}_k$ for $k = 7$ to 11). For substitute commodities used to make retail food products, the output is produced with CES production technology by combining two inputs, which are themselves composite inputs, which are aggregate agricultural inputs and marketing inputs. The structure of the equation follows the GTAP-AGR nested CES model (GTAP, 2005). The individual commodities included as a composite input are assumed to be separable. The first input is an agricultural commodity aggregate. Change in demand for the composite agricultural commodity ($\hat{x}_i^{ag}$) used to produce retail commodity i when agricultural commodities and marketing inputs are substitutable is:

$$(80 - 88)\ \hat{x}_i^{ag} = \hat{q}_i + \sigma \cdot (\hat{p}_i - \hat{p}^{ag}) \qquad \text{for } i = 1 \text{ to } 9$$

with σ the elasticity of substitution between aggregate agricultural commodities and marketing inputs and $\hat{p}^{ag}$ the proportionate change in the composite price for an agricultural commodity. The proportionate change in the composite price is:

$$(89 - 97)\ \hat{p}_i^{ag} = \sum_{k=1}^{11} SR_k^i \cdot \widehat{w}_k \qquad \text{for } i = 1\ to\ 9$$

where SR_k^i are input cost shares of producing retail good i attributed to the kth agricultural output.

Marketing inputs ($\hat{x}_{12}$) are the second composite input. Change in demand for marketing inputs used to produce retail good i is modified from Equation (64) and includes the substitution elasticity σ between agricultural and marketing inputs:

$(64') \ \hat{x}_{12} = \sum_{i=1}^{9} SC_{12}^{i} \cdot \hat{q}_i + \sigma \cdot (\hat{p}_i - \widehat{w}_{12})$

The aggregated agricultural commodity is produced with CES production technology by combining crop and livestock inputs. Changes in the total crop and livestock demand for retail good i are:

$(98-106) \ \ \hat{x}_i^{crop} = \ \hat{x}_i^{ag} + \sigma^{ag} \cdot (\hat{p}_i^{ag} - \hat{p}_i^{crop})$ for $i = 1$ to 9

$(107-115) \ \ \hat{x}_i^{anim} = \ \hat{x}_i^{ag} + \sigma^{ag} \cdot (\hat{p}_i^{ag} - \hat{p}_i^{anim})$ for $i = 1$ to 9

where σ^{ag} is the elasticity of substitution between crop and livestock outputs (Figure 2.3, Chapter 2), and $\hat{p}_i^{crop}$ and $\hat{p}_i^{anim}$ are the proportionate change in the composite prices for crop and livestock products used to produce retail good i, respectively, which are calculated as:

$(116-124) \ \ \hat{p}_i^{crop} = \sum_{k=1}^{2} SR_k^i \cdot \widehat{w}_k$ for $i = 1$ to 9

$(125-133) \ \ \hat{p}_i^{anim} = \sum_{k=3}^{6} SR_k^i \cdot \widehat{w}_k$ for $i = 1$ to 9

Since the individual commodity in each of these composite inputs is assumed to be separable from one another, changes in the demand for oil crop and grain commodities are estimated using these composite inputs and price changes. As a result, Equations $(53-54)$ modified as follows:

$(53'-54') \ \hat{x}_k = \sum_{i=1}^{9} SC_k^i \cdot \hat{x}_i^{crop} + \sigma^c \cdot (\hat{p}_i^{crop} - \widehat{w}_k)$ for $k = 1, 2$

where SC_k^i and SC_2^i are costs shares of the kth farm product used by the retail sector i and σ^c is the elasticity of substitution between oil crop and grains (Figure 2.3, Chapter 2). Similarly, the change in demand for livestock commodities, between cattle, pork, dairy, and poultry and eggs (Figure 2.3, Chapter 2) is modified by Equations $(55'-58')$ as follows:

$(55'-58') \ \hat{x}_k = \sum_{j=1}^{9} SC_k^i \cdot \hat{x}_i^{anim} + \sigma^l \cdot (\ \hat{p}_i^{anim} - \widehat{w}_k)$ for $k = 3 \ to \ 6$

where σ^l is the elasticities of substitution between these commodities.

For grains other than soybean, their demand by food processers in the retail sector is a function of aggregate demand for grains and the substitutability among grain prices. Changes in demand for grains are determined after modifying Equations 37 to 42:

$$(37' - 42')\ \hat{x}_k^F = \hat{x}_2 + \sigma^f \cdot (\hat{p}^{cropf} - \widehat{w}_k) \qquad \text{for } k = 14\ to\ 19$$

where σ_{FF} is the elasticity of substitution between crops for food processing, and $\hat{p}_j^{cropf}$ is the composite price for crops for food processing (Figure 2.3, Chapter 2). The composite price of grains used to make food is:

$$(134)\ \hat{p}^{cropf} = \sum_{k=14}^{19} S_k \cdot \widehat{w}_k$$

where S_k are cost shares for corn, wheat, rice, barley, oats, and sorghum. Changes in demand for feed crops, including soybeans, are derived from the aggregate demand for feed grains and the substitution possibility between them. Changes in the demand for feed crops for feed are determined by modifying Equations 72 to 78:

$$(72' - 78')\ \hat{x}_k^A = \sum_{m=3}^{6} SM_k^m \cdot \hat{x}_m + \sigma^a \cdot (\hat{p}^{feedg} - \widehat{w}_k) \qquad \text{for } k = 13\ to\ 19$$

where SM_k^m is the quantity share of the total amount of animal feed grain k used by the livestock sector m and σ^a is the elasticity of substitution between feed grains (Figure 2.3, Chapter 2). The composite price for grains used to feed animals is:

$$(135)\ \hat{p}^{feedg} = \sum_{k=13}^{19} \sum_{m=3}^{6} SA_k^m \cdot \widehat{w}_k$$

where SA_k^m are the cost shares of livestock commodity m used by animal-feed grain k.

For the economic shock of one single year, Model 3 consists of 59 equations for ERM structure (Equations $(1-36), (43-52), (59-63), (65-71), (79)$), and 76 equations for the nested CES production technology (Equation $(37'-42'), (53'-58'), (64'), (72'-78')(80-135)$). This model consists of 135 vectors of endogenous variables and a 135×135 matrix of cost shares and elasticities.

Welfare Calculations

The change in consumer and producer surplus caused by the change caused by the economic shocks is calculated using Lusk (2017)'s, Okrent and Alston (2012)'s, and Wohlgenant (2011)'s second-order approximation:

$$(136)\ \Delta CS = \sum_{i=1}^{9} -P_{i,0} \cdot Q_{i,0} \cdot (\hat{p}_i + \delta_i) \cdot \left(1 + 0.5 \cdot \sum_{j=1}^{9} \mathrm{H}_{ij} \cdot \hat{p}_j\right)$$

where $P_{i,0}$ and $Q_{i,0}$ are the prices and demand for retail good i in the initial equilibrium, δ_i is a demand shock, and H_{ij} is the compensated elasticity of demand[6] calculated with the uncompensated elasticity of demand, expenditure share of the retail product, and expenditure elasticity. It is important to note that the ERM solves for δ_i. An approximation of the change in farm producer surplus is:

$$(137)\ \Delta PS = \sum_{k=1}^{24} w_{k,0} \cdot x_{k,0} \cdot (\widehat{w}_k + \varphi_k) \cdot (1 + 0.5\hat{x}_k)$$

where $w_{k,0}$ and $x_{k,0}$ are the price and demand farm commodity k in the initial equilibrium and φ_k is the estimated economic shock affecting farm commodity k. It is important to note that the ERM solves for φ_k. The quantity of feed grains, including soybean, corn, wheat, rice, barley, oats, and sorghum, are used for food processing, export, and animal feeding. Corn is also used for ethanol production. Therefore, Changes in foreign consumer surplus accruing to importers of feed grains and changes in ethanol producer and consumer surplus are, respectively:

$$(138)\ \Delta IS = -\sum_{k=13}^{19} w_{k,0} \cdot x_{k,0}^{T} \cdot \widehat{w}_k \cdot (1 + 0.5 \cdot \hat{x}_k^{T})$$

$$(139)\ \Delta ETH = -w_{k0} \cdot x_{13,0}^{E} \cdot \widehat{w}_k \cdot (1 + 0.5 \cdot \hat{x}_{13}^{E})$$

where $w_{k,0} \cdot x_{k,0}^{T}$ is the export value of grain commodity k in the initial equilibrium and $w_{k0} \cdot x_{13,0}^{E}$ is the value of ethanol production, also in the initial equilibrium.

Macroeconomic effects and Agri-industrial Shocks

Sector-specific shocks from the ERM are regressed against macroeconomic variables to determine if there is a relationship between those variables and the shocks. Variables include per

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[6] $\mathrm{H}_{ij} = \eta_{ij} + s_j \cdot \eta_i^{E}$ with η_{ij} demand elasticity for retail good i with respect to the price of good j, s_j expenditure share of retail good j, and η_i^{E} expenditure elasticity of retail good i.

capita gross domestic product (GDP) and an energy price index (EPI) from 1993 to 2019. Separate regressions are run for each sector and GDP or energy price index as linear-log models. The linear-log regression equations are:

(140) $shock_{it} = a_i + b_i \cdot \ln x_t + \varepsilon_{it}$ for $i, t = 1$ to 27

where $shock_{it}$ is an estimated shock for i commodity from the ERM given t year, x_i is GDP or EPI for t year, (a_i, b_i) are parameters to be estimated for i commodity, and ε_{it} is a random error term with an expected value of zero and a constant variance. In all, there are 54 regressions with 27 retail and agricultural commodities and 2 macro variables. The change in the shock, given a 1% change in the GDP or the energy price index is $\frac{b}{100}$ (Wooldridge, 2021).

Bootstrap Sampling

A bootstrap sampling procedure method is conducted to generate an empirical distribution of estimates to determine the confidence intervals of the estimate. The estimated coefficients of econometric indicators of 27 sector-specific shocks ($\hat{b}_i$, i = 1 to 27) are resampled with replacement . This procedure is repeated 500 times to obtain 500 bootstrap samples of b_i^*. This bootstrap method provides an estimate of the sampling distribution of semi-elasticity from the empirical distribution obtained from the sample.

The average value of 500 bootstrap samples is used as an exogenous shock in the EDM structure for estimating changes in price and quantity in the US food industry and social welfare due to 1% changes in macroeconomic indicators. The confidence intervals of the estimate are used to determine whether macroeconomic indicators are appropriate variables to account for changes in retail food and agricultural markets.

Data

To estimate the sector-specific shocks driving the year-to-year changes in prices and quantities, farm products and price index data of the agricultural commodity market were collected to match the period of price and demand data of the retail food market (Table 3.1). Data on the year-per-year price and quantity changes of retail food products are calculated as a proportionate change. The consumer price indexes for personal consumption expenditures on food goods are from the National Income and Product Accounts of the Bureau of Economic Analysis (BEA, 1993 to 2021). Demand quantity data are calculated by dividing personal consumption expenditures by the price index (BEA, 1993 to 2021).

Table 3.1. Consumer price index and personal consumption expenditure (2021)

Commodity	Expenditure (million $)	Price index (2012=100)
Cereal	176,428 (7.73)[1]	107.64 (6.47)
Meat	216,153 (6.63)	122.38 (5.33)
Eggs	15,585 (7.54)	103.11 (1.93)
Dairy	89,721 (7.51)	105.95 (2.91)
Fruit and Vegetable	143,751 (6.64)	109.60 (5.87)
Other food	294,887 (8.29)	109.43 (2.79)
Non-alcoholic beverages	118,173 (9.19)	109.40 (1.81)
Alcoholic beverages	180,776 (8.31)	110.22 (5.77)
FAFH[2]	758,912 (26.69)	131.13 (6.47)

Source: U.S. Bureau of Economic Analysis (BEA), National Income and Product Accounts, Table 2.4.4U. Price Indexes for Personal Consumption Expenditures by Type of Product, Table 2.4.5U. Personal Consumption Expenditures by Type of Product

Note 1) Numbers in parentheses are the percentage change over the previous year.

2) Food-Away-From-Home.

Table 3.2 shows the producer price index and agricultural commodity supply in 2021. The supply quantity for livestock is from the Livestock and Meat Domestic tables compiled by the U.S. Department of Agriculture-Economic Research Service (USDA-ERS, 1993 to 2021). Dairy supply quantity data are from the Dairy Data tables, also complied by USDA-ERS (USDA-ERS, 1993 to 2021). Fish quantity data are from the value of consumption expenditure for fish divided by the price index (BEA, 1993 to 2021). The value for the supply of marketing inputs is the sum of gross margins for the wholesale trade of grocery and gross margins for retail firms of grocery stores from the U.S. Census Bureau (U.S. Census Bureau, 1993 to 2021). The supply quantity data for the remaining farm commodities are from the USDA's Vegetables and Pulses, Fruit and Tree Nuts, Sugar and Sweeteners, Oil Crops, Feed Grains, Wheat, and Rice Yearbook (USDA-ERS, 1993 to 2021).

Table 3.2. Producer price index and agricultural commodity supply (2021)

Commodity	Supply quantity[1]			Producer price index (2012=100)[2]	
Vegetables & melon	million lbs	52,195	(-0.20)	188.85	(0.5)
Fruits & tree nuts	million lbs	26,387	(-3.47)	532.11	(-11.8)
Sugarcane & sugar beet	million lbs	12,416	(2.04)	177.80	(3.4)
Peanut	1,000 tons	3,391	(1.00)	108.37	(6.4)
Fish[3]	million $	19,657	(7.57)	554.31	(27.9)
Marketing[4]	million $	335,142	(8.46)	163.21	(3.1)
Soybean	million bushels	4,422	(-1.81)	256.13	(45.8)
Corn	million bushels	14,789	(6.14)	242.51	(69.0)
Wheat	million bushels	2,048	(1.08)	214.76	(44.4)
Rice	million cwt	245	(3.53)	109.74	(4.9)
Barley	million bushels	182	(0.20)	253.54	(43.3)
Oats	million bushels	144	(3.57)	288.42	(47.8)
Sorghum	million bushels	382	(2.01)	280.88	(67.5)
Cattle	million lbs	37,329	(0.91)	181.04	(11.3)
Pork	million lbs	21,859	(-1.18)	118.24	(56.2)
Dairy	million lbs	221,000	(1.66)	206.03	(1.9)
Poultry	million lbs	42,913	(0.57)	269.82	(38.5)
Eggs	million dozen	7,765	(-1.60)	162.10	(17.0)

Source: 1) U.S. Department of Agriculture, Economic Research Service, Product Yearbook (2021), Dairy Data (2021) (https://www.ers.usda.gov/data-products)

2) U.S. Bureau of Labor Statistics, Producer Price Indexes (PPI)

3) U.S. Bureau of Economic Analysis, National Data.

4) The sum of gross margins for ‘wholesale trade-grocery and related products’ and ‘retail firms-grocery stores.’ And detailed data are available from the U.S. Census Bureau (census.gov).

Note: Numbers in parentheses indicate the percentage change over the previous year.

The changes in the supply of farm products are calculated as proportionate changes compared to the previous year using these supply quantities. In the same way, the changes in the price of farm products are calculated as a proportionate change compared to the previous year using the producer price index from the U.S. Bureau of Labor Statistics (BLS, 1993 to 2021).

Elasticities and Cost Shares

Elasticities for food demand, farm supply, grain exports, and ethanol demand are the same values reported in Chapter 2 (Table 2.2, Table 2.5). Demand elasticities for retail food products are from Lusk (2017) and Okrent and Alston (2011). The elasticity of supply for fruit and tree nuts is from Chavas and Cox (1995). The elasticity of supply for fish is from Okrent and Alston (2012). The elasticity of supply for marketing is from Lusk (2012). The elasticities of supply of the rest of the farm commodities come from Dubman (2008). The elasticities of export for feed grains are from Harrington and Dubman (2008), and the elasticity of ethanol demand is from Schmitz et. al (2007). The farm-retail product shares (Table 2.3, Chapter 2) and farm-commodity shares (Table 2.4, Chapter 2) come from Okrent and Alston (2011).

Farm Commodity Supply and Usage

The supply shares of crops for food are required to calculate the changes in the price of oil crops and grains. The cost shares are calculated using the value of production of each feed grain and the share of supply used by food processors (Table 2.7, Chapter 2). To calculate the change in the price of livestock commodities, the cost shares of the animal inputs of producing livestock commodities are needed. The cost share of the animal inputs is the value subtracting the cost of feed grain used for animal feeding from the livestock supply value (Table 2.8, Chapter 2). Lastly, the change in feed grains supply for meat products is calculated value of crop production, the share of crop usage for feed, and the supply share of feed for each animal product (Table 2.8, Chapter 2). The data used to calculate the supply share for each usage purpose come from the Products Yearbook (Oil crop, Feed grains, Wheat, and Rice Yearbook) compiled by USDA-ERS (USDA-ERS, 2022). The dataset for shares of farm supply and usage generates time-series data to use values that correspond to the given year for the analysis. For example, the estimation of economic shocks in 1993 used the share of supply and usage in 1993 for all farm commodities.

Elasticities of Substitution

The substitution elasticity between farm products and marketing inputs is 0.45 and calculated as the weighted average of substitution elasticities for beef, pork, poultry, eggs, dairy, and vegetable reported by Wohlgenant (1989). The weights are the variances calculated using t-values reported in Wohlgenant's study (Table 2.10). As mentioned in Chapter 2, although a few studies report substitution possibilities between animal and plant-based proteins (Day, 2013; Sabate and Soret, 2014; Ismail et al., 2020), no previous literature reports elasticities of substitution between grains and livestock. There is limited substitution because these products are highly differentiated. It goes back to the Leontief technology and complementarity. Grains and livestock are nearly perfect complements. For this reason, this study assumes that the elasticity of substitution between livestock and grains (σ^{ag}) is relatively low (0.01). The substitution elasticity between oil grains and grains is 0.26 and the elasticities between food processing grains and between feed grains are also 0.26 (GTAP, 2016), and the substitution elasticity between animal inputs is 0.08 (Suh and Moss, 2017).

Gross Domestic Product and Energy Prices

Gross Domestic Products (GDP) and Energy Price Index (EPI) from 1993 to 2019. Table 3.3 shows the macroeconomic indicators used to estimate the semi-elasticities. GDP data is from the National Dataset of the U.S. Bureau of Economic Analysis (U.S. BEA, 1993 to 2021). The population data is from the World Population Prospects 2019 Dataset of Unites Nations (UN, 2019). Consumer Price Index (CPI) is from the U.S. Bureau of Labor Statistics (U.S. BLS, 1993 to 2021). EPI is from the U.S. Bureau of Labor Statistics (U.S. BLS, 1993 to 2021). The real GDP per capita is calculated that dividing GDP by the population and then multiplying CPI.

Table 3.3. Macroeconomic indicators (2021)

Indicator	Unit	Value
Gross Domestic Product[1]	billions $	22,996
Population[2]	thousands	332,915
Consumer Price Index[3]	1982-84=100	270.97
Energy Price Index[4]	1982-84=100	238.33

Note: [1] U.S. Bureau of Economic Analysis (2021), National Data, Table 1.1.5. Gross Domestic Product.

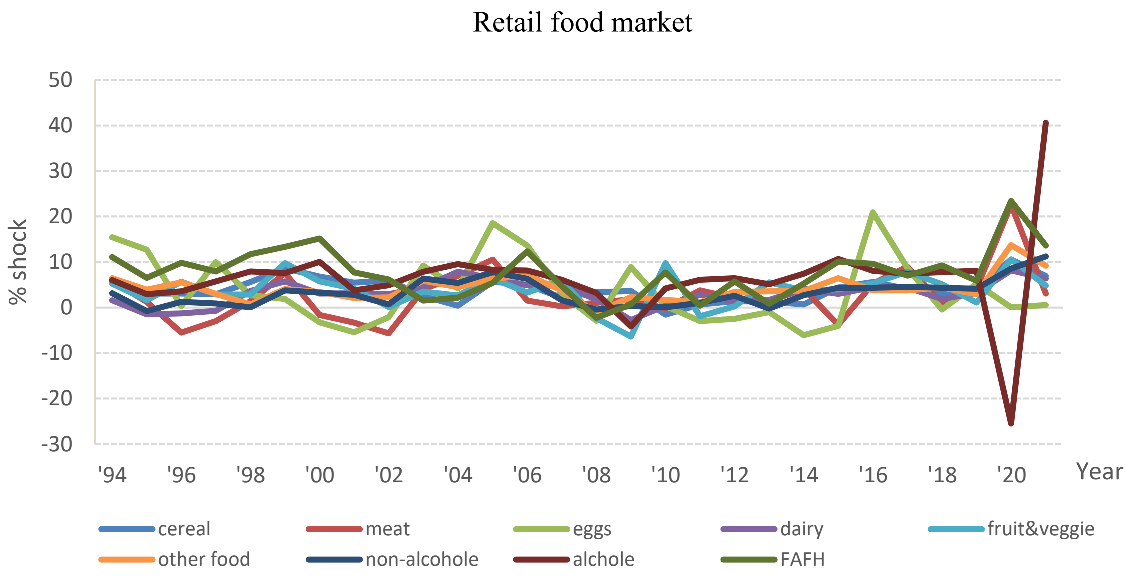
[2] United Nations, World Population Prospects 2019 (https://population.un.org/wpp/).

[3] U.S. Bureau of Labor Statistics (2021), CPI for All Urban Consumers-All items.

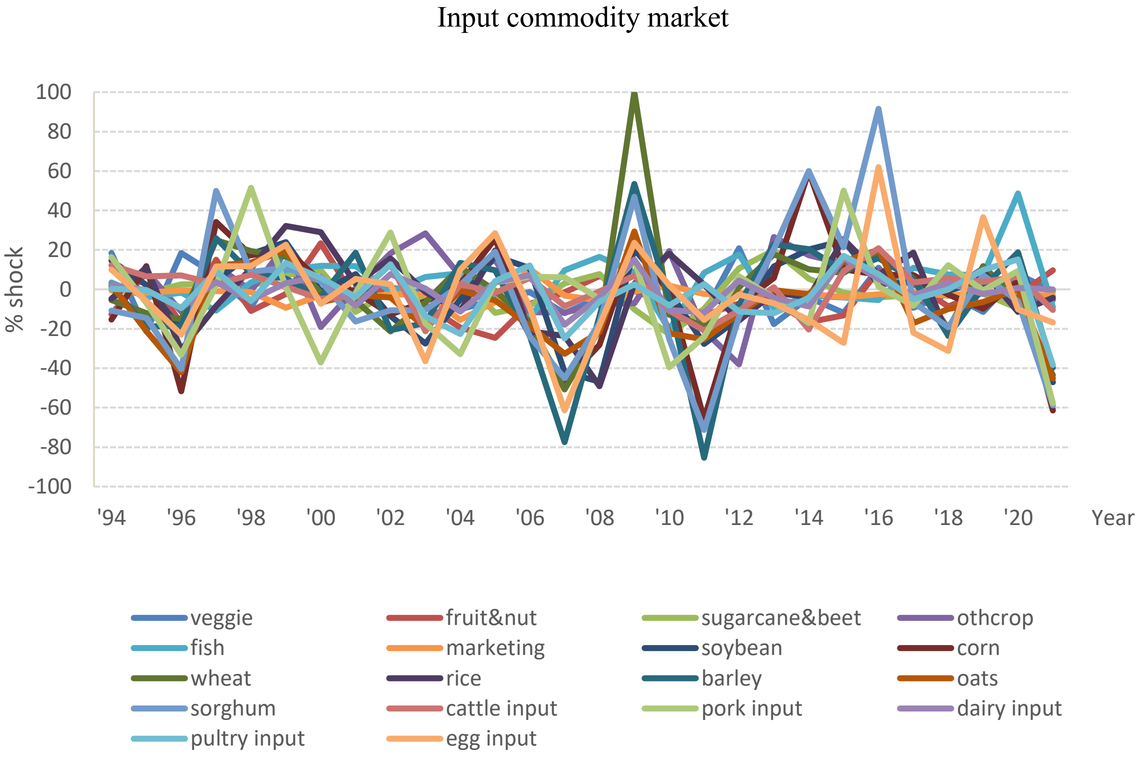
[4] U.S. Bureau of Labor Statistics (2021), CPI for All Urban Consumers-Energy in U.S. city average.

Results

Economic shocks driving year-to-year changes in prices and quantities in the US food industry over the past 28 years were estimated with the ERM (Figure 3.2). Shocks in the retail food market represent a shift in consumer demand for food products (Figure 3.3). Table 3.4 shows the estimated shocks for the retail food market for 2019-2021. The retail food market experienced an enormous shock in 2020 and 2021 due to the COVID-19 pandemic. In 2020, household food consumption for retail food products increased as people were quarantined during the outbreak. The increase in demand for meat products and alcoholic beverages was the largest with 22.6% and 23.42% while the demand shocks for Food-Away-From-Home (FAFH) dropped sharply to 24.46% (Table 3.4). In 2021, the demand shock for FAFH soared to 40.59% due to the government’s fiscal policy to boost the national economy and the end of the lockdown caused by COVID-19.



Retail food market



Input commodity market

Figure 3.2. Estimated shocks for the retail food and agricultural commodity markets

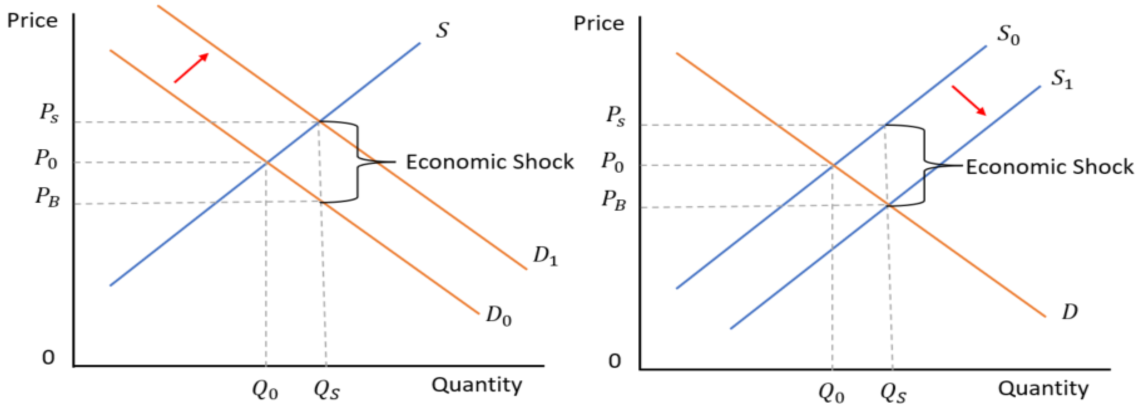


Figure 3.3. A shift in demand and supply and economic shocks

P_0, Q_0: initial price and quantity
P$_S$: price sellers receive
P$_B$: Price buyers pay

Table 3.4. Estimated shocks in demand for the retail food market (%), 2019-2021

Commodity	2019	2020	2021
Cereal	4.15	10.56	6.93
Meat	4.24	22.62	3.08
Eggs	5.22	00.08	0.58
Dairy	3.24	08.17	6.40
Fruits & Vegetables	1.09	10.57	4.86
Other foods	2.98	13.72	9.22
Non-alcoholic beverages	4.11	08.57	11.24
Alcoholic beverages	5.91	23.42	13.61
Food-Away-From-Home	8.10	-25.46	40.59

The estimated shocks in the agricultural commodity market represent a shift in the supply of agricultural commodities (Figure 3.3). Several points in time are notable in the figure. For example, the world food price crisis in 2007-2008 affected the supply of US crop commodities, and the widespread drought in 2011 affected grain production. These shocks have knock-on effects on other sectors that use these commodities in the production of animal feeds, cereals, and other goods. The supply shock associated with poultry and eggs in 2016 may be attributed to the avian influenza outbreak.

Table 3.5 summarizes the shocks in the agricultural commodity market, from 2019 to 2021, which are largely attributable to COVID-19. In 2021, shocks were negative except for fruits and tree nuts. These impacts may be related to labor shortages and supply chain disruptions. Feed grains like soybeans, corn, wheat, sorghum, and oats had a larger supply shock than other sectors due to the negative shock on livestock products and worsening export market conditions. For example, the shock of supply was -61.34% for corn, -58.82 for sorghum, and -47.07% for soybean. For livestock commodities, the shock of supply was -57.70 for pork inputs, -38.31% for poultry inputs, -16.82% for egg inputs, and -10.42% for cattle input.

Table 3.5. Estimated shocks for the agricultural commodity market (%), 2019-2021

Commodity	2019	2020	2021
Vegetables & melon	-11.49	7.61	-0.71
Fruits & tree nuts	-01.61	-2.95	9.72
Sugarcane & sugar beets	-2.22	-9.69	-1.25
Peanuts	10.63	-3.19	-5.20
Fish	7.24	48.65	-8.99
Marketing	-1.01	-2.63	-3.07
Soybean	4.52	0.22	-47.07
Corn	-9.85	4.11	-61.34
Wheat	11.81	-5.69	-43.59
Rice	9.23	-11.45	-4.23
Barley	1.13	18.71	-39.63
Oats	-6.38	0.16	-45.15
Sorghum	7.23	-6.06	-58.82
Cattle	3.79	6.50	-10.42
Pork	-0.48	9.27	-57.70
Dairy	-2.29	0.71	-0.02
Poultry	9.80	15.27	-38.31
Eggs	36.56	-10.12	-16.82

Negative economic shocks to the US food industry reduced social welfare, in 2007-2008 and 2011-2012, when the global food crisis occurred (Dawe, 2009; USDA, 2009; Council on Foreign Relations, 2013), and in 2020, when the supply was disrupted due to the COVID-19 pandemic (Figure 3.2 and Figure 3.4). However, the trend of aggregate effects of economic shocks in the retail food and agricultural commodity markets from 1994 to 2021 demonstrates that, despite fluctuations, change in overall social welfare induced by shocks to the US food industry has continuously been positive (Figure 3.4).

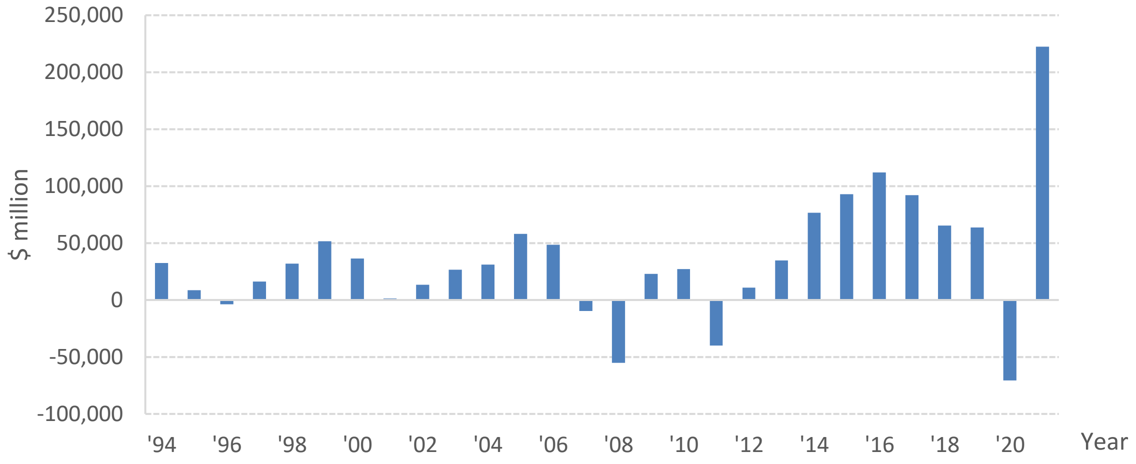


Figure 3.4. Aggregate effects of the shocks to the US food industry, 1994-2021

Table 3.6 reports the aggregate effects of economic shocks in all segments related to the US retail food and agricultural commodity market focusing on food processing for the recent three years. The change in social welfare due to the economic shock in 2019 was $63 billion, but it fell to $70.5 billion due to the worsening COVID-19 situation in 2020. Since then, the change in social welfare has rebounded to $222.3 billion in 2021, as domestic consumer purchases of food products increased. Despite supply disruptions, producer surplus increased due to the government's response to helping farmers and strong consumption of retail food. On the other hand, a surplus of foreign consumers of export grains and corn buyers for ethanol production decreased due to external shocks in 2021 (Figure 3.5).

Table 3.6. Aggregate effects of economic shocks

Change in Surplus (million $)	2019	2020	2021
Domestic food consumers	59,622	-81,903	251,645
Domestic agricultural producers	4,925	12,379	9,754
Foreign consumers	659	-1,843	-23,801
Ethanol market related	-1,417	845	-15,340
Total Welfare	63,789	-70,523	222,258

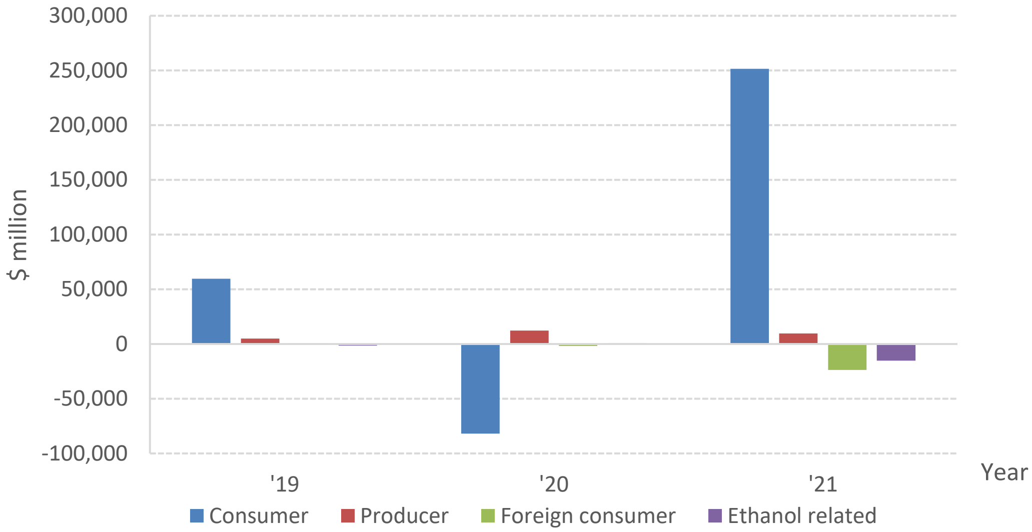


Figure 3.5. Surplus effects of the shocks to the US food industry, 2019-2021

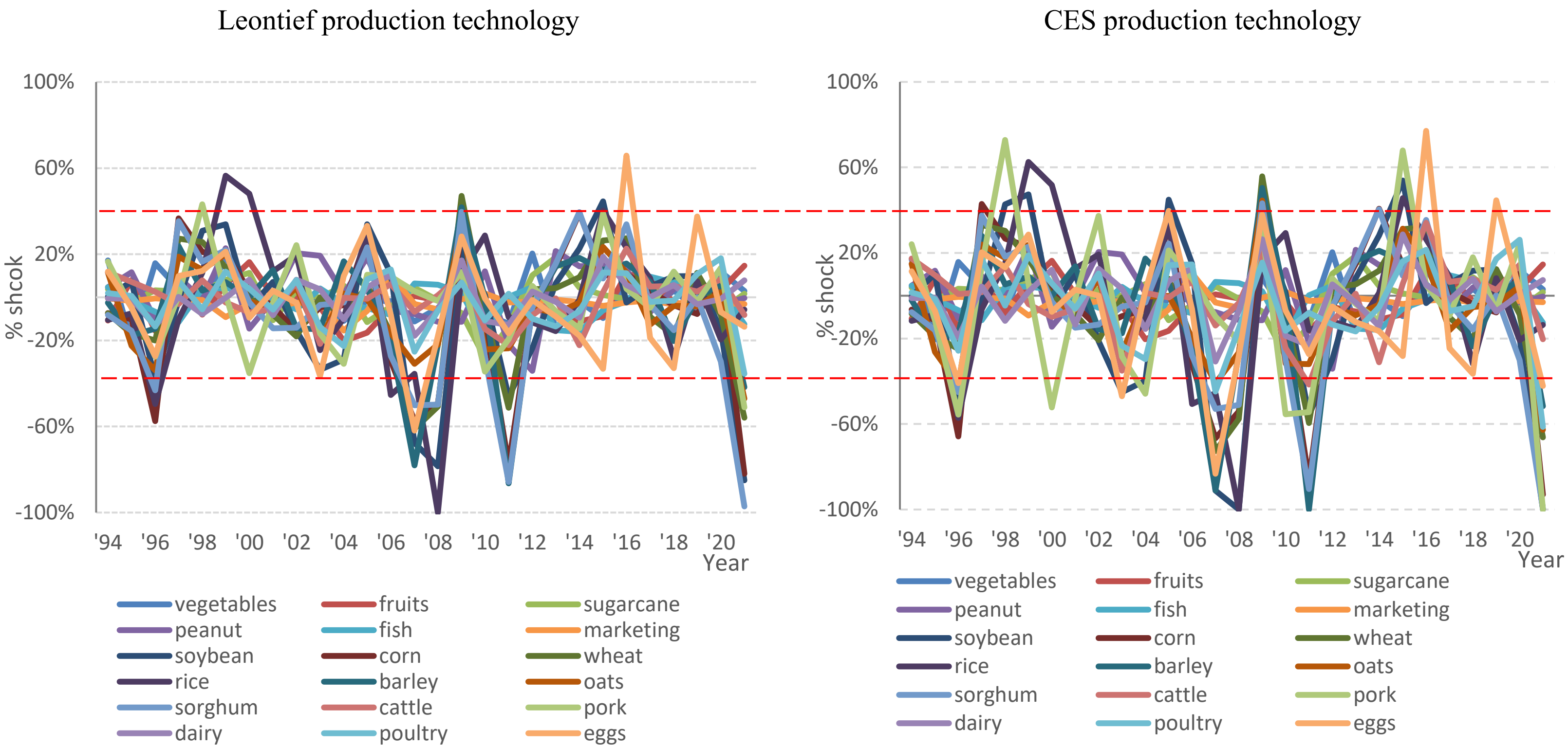
Relationship between substitutability and economic shocks

The relationship between the substitutability of agricultural commodities for food processing and the economic shocks is tested by comparing the Leontief and nested CES production technology. Accordingly, there is no substitute relationship between vegetables and melon, fruits and tree nuts, sugarcane and sugar beet, peanut, and fish even in the nested CES model, so the estimated shocks are the same as the Leontief model. The possibility of substitution between aggregate agricultural commodities and marketing inputs was considered, but there was no difference in the estimate of the shock. (Table 3.7). As shown in Table 7 and Figure 3.6, if producers adjust the supply of agricultural commodities within observed price changes, the market can tolerate more shocks when producers can technically change the proportion of agricultural commodities used for food processing. For example, when estimating the economic shock in 2020 driving the agricultural price change, the supply shock of cattle input in the Leontief model was -8.14%, while in the nested CES model was -20.32% by allowing substitution between grains, livestock, and feed grains. Intuitively, if there were the possibility of substitution between agricultural products, then producers would want to make mitigate price fluctuations by controlling the proportion of agricultural commodities for food production when the supply shocks affect the agricultural market.

Table 3.7. Estimated shocks under different production technology

	Estimated shocks (%) for the input commodity market (2020)	
Commodity	Leontief	CES
Vegetables & melon	-0.71	-0.71
Fruits & tree nuts	9.72	9.72
Sugarcane & sugar beet	-1.25	-1.25
Peanut	-5.20	-5.20
Fish	-8.99	-8.99
Marketing	-3.07	-3.07
Soybean	-85.03	-100.00
Corn	-81.97	-93.01
Wheat	-55.90	-66.24
Rice	-5.70	-13.67
Barley	-41.83	-51.66
Oats	-47.08	-62.71
Sorghum	-97.16	-99.48
Cattle	-8.14	-20.32
Pork	-51.12	-100.00
Dairy	7.92	07.27
Poultry	-35.52	-61.33
Eggs	-13.74	-42.13

Note: For CES assumption, $\sigma = 0.45$, $\sigma^{ag} = 0.01, \sigma^{c}, \sigma^{f}, \sigma^{a} = 0.26, \sigma^{l} = 0.08$.



Leontief production technology

CES production technology

Figure 3.6. Relationship between substitutability and shocks

Note: For all CES models, $\sigma = 0.45$, $\sigma^{ag} = 0.01, \sigma^{c}, \sigma^{f}, \sigma^{a} = 0.26, \sigma^{l} = 0.08$.

Estimated shocks, energy prices, and GDP

Table 3.8 shows the estimated coefficients, i.e. the semi-elasticities of the macro-economic indicators with respect to the economic shocks in the retail food and agricultural commodity markets. An increase in GDP is positively associated with demand shocks for all retail food products. An increase in energy prices is negatively associated with shocks for all goods but non-alcoholic beverages and Food-Away-From-Home. The effect of GDP on the change in the shock for cereal, dairy, non-alcoholic beverages, and alcoholic beverages is statistically significant. For example, given a 1% change in the GDP, the change in the demand shock of cereal is 0.8313 and 0.9298 for dairy consumption. Alcoholic beverages were the most responsive retail food category to increases in GDP (1.2219) and energy prices (-0.1484). The effect of EPI on the change in the shock for retail demand for fruits and vegetables, and farm-level supply of peanut, and rice are statistically significant. For example, given a 1% change in the EPI, the change in the demand shock of fruits and vegetables is -0.224, the supply shock of peanuts is -0.8248, and -0.8103 for rice. The supply shocks associated with agricultural products were mostly positively affected by GDP growth and negatively affected by an increase in energy prices, but they were not statistically significant. Figure 7 shows the volatility of the retail food demand shifts and farm supply shifts. The results indicate that macroeconomic indicators such as GDP and EPI are insufficient to account for the impact on agricultural production when compared to retail food demand.

Table 3.8. Effects of macro-economic indicators

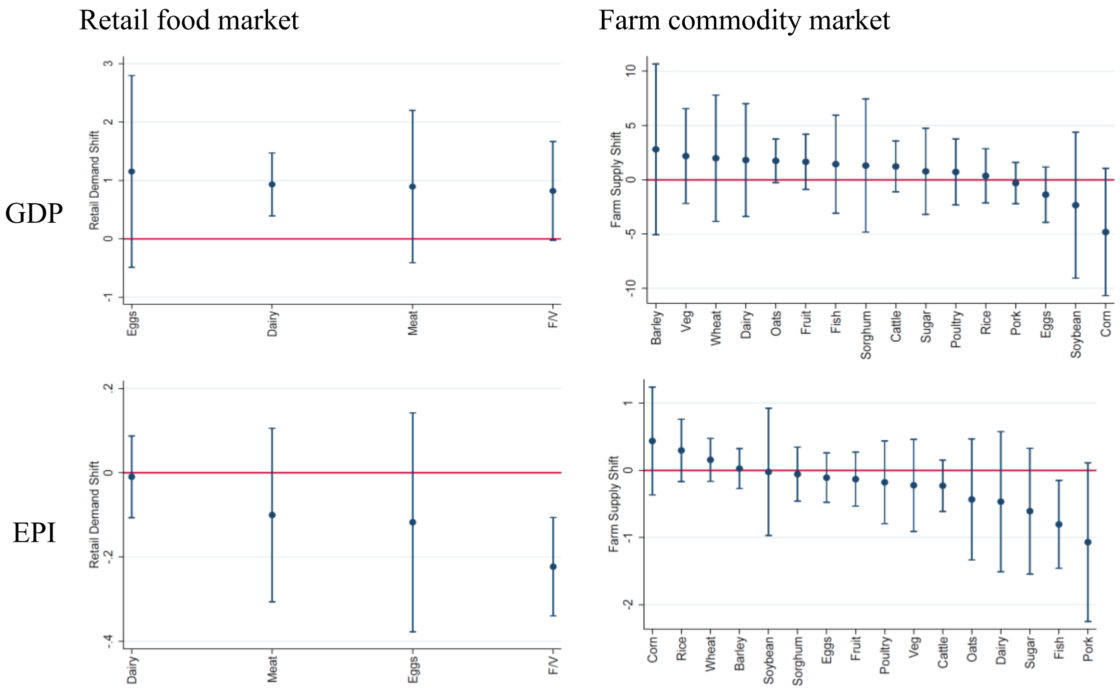
Commodity	Real Gross Domestic Production	Energy Price Index
Retail food market		
Cereal	0.831**	-0.009
Meat	0.870	-0.1000
Eggs	1.150	-0.115
Dairy	0.930**	-0.008
Fruits and Vegetables	0.819	-0.224**
Other foods	0.448	-0.015
Non-alcoholic beverages	0.693*	0.009
Alcoholic beverages	1.222*	-0.148
Food-Away-From-Home	1.127	0.021
Agricultural commodity market		
Vegetables & melon	-1.413	-0.046
Fruits & tree nuts	0.342	-0.219
Sugarcane & sugar beet	1.750	0.163
Peanut	0.715	-0.825**
Fish	0.786	0.297
Marketing	-0.548	-0.011
Soybean	2.232	-0.202
Corn	1.152	-0.621
Wheat	-4.827	-0.016
Rice	1.304	-0.810*
Barley	-2.215	-0.449
Oats	0.792	-0.184
Sorghum	3.011	-1.038
Cattle	1.303	-0.114
Pork	2.004	0.409
Dairy	-0.286	0.029
Poultry	1.748	-0.132
Eggs	1.939	-0.433

Note: Number of observations: 27.

The value of effects is the average of 500 bootstrap resampling.

** p-value ≤ 0.05

* p-value ≤ 0.1



Retail food market

Farm commodity market

GDP

EPI

Figure 3.7. The confidence intervals of demand and supply shifts

Changes in prices and quantities for the retail food and agricultural commodities were estimated by utilizing the effect of GDP and EPI as exogenous shocks in the EDM. From the estimated price and quantity changes in EDM, aggregate change in social welfare caused by the change in macro-variables is calculated as shown in Table 9. The change in social welfare is calculated using Lusk (2017)'s, Okrent and Alston (2012)'s, and Wohlgenant (2011)'s second-order approximation. The overall change in social welfare in the US food industry from a 1% increase in GDP is estimated to be $8,433 million, and the social welfare loss due to a 1% increase in EPI is estimated to be $1,395 million. The increase in retail food consumer surplus in the US food industry due to a 1% increase in GDP is $5,822 million, and the increase in agricultural producer surplus is $2,249 million. The increase in GDP indicates a more favorable shock for a consumer than a producer, as the change in consumer surplus from the increase in GDP is much more than those for the producers. Similarly, the loss of consumer surplus due to rising EPI is much greater than that of procedures. The decrease in retail food consumer surplus in the US food industry due to a 1% increase in EPI is $954 million, and the decrease in agricultural producer surplus is $249 million. These results support those macroeconomic indicators are insufficient as factors determining the shock in the agricultural market, while retail food demand is more affected by changes in macro-economic indicators.

Table 3.9. Aggregate effects of change in the macro-economic index

Changes in Surplus (million $)	Real Gross Domestic Production	Energy Price Index
Domestic food consumers	5,822	-954
Domestic agricultural producers	2,249	-249
Foreign consumers	186	-82
Ethanol market related	176	-110
Total welfare	8,433	-1,395

Conclusion

This study quantified the sector-specific shocks driving changes in prices and quantities in the US food industry and evaluated the changes in social welfare for each segment using a model that links the 24 agricultural commodities with nine retail food categories. The shocks estimated with the ERM were used for describing follows. First, the overall change in social welfare caused by inflation driven by COVID-19 was evaluated. Recently, the change in annual social welfare plunged to $70.5 billion in 2020 and then recovered to $222.3 billion in 2021. The result implies that the government's massive fiscal spending to stabilize the economy in reaction to the COVID-19 pandemic has caused inflation by boosting demand that had been stifled by the pandemic turmoil. The tendency of the change in total social welfare in the US food industry with respect to economic shocks is shown to increase continuously, except in 2008, 2011, and 2020, when there was a global economic crisis. Second, this study identified the relationship between the substitutability of agricultural commodities for food processing and the economic shocks by comparing the Leontief and nested CES production technology. Allowing for input substitutability significantly impacts estimates of changes in welfare due to external shocks. Lastly, evaluating the impact of changes in macro-economic variables on the economic shocks in the US food industry and social welfare, the overall benefits in social welfare due to an increase in GDP were estimated to be $8.4 billion and the loss due to an increase in energy price was estimated to be $1.4 billion. Agriculture products exhibited great dispersion and volatility, which suggests that the supply of agricultural products is influenced by a variety of exogenous factors rather than a change in the macro-economic variable. Retail food products exhibited a more pronounced response of supply shift to changes in macro-economic variables.

This study evaluates the changes in social welfare for agricultural producers and food consumers using a model that links the agricultural producer with the retail food consumer, but the intermediate processor and retail provider, between producer and consumer, is not taken into account in the model. The segment for intermediate suppliers in the supply chain belongs to producer surplus and is not separately described. Further research could focus on changes in the welfare of intermediate suppliers by establishing a linkage model between agricultural producers and intermediate suppliers. The EDM also assumes there are no limitations on production. Even though production is inelastic in the short term because it is difficult for producers to significantly increase or decrease production in the short term, the capacity of producers to adjust supply quantity was not considered. The limitations of this model could be tested in consequent studies by analyzing farmers' behavioral decisions depending on the short-term and long-term elasticity.

This study extended the conventional EDM by implementing ERM to recover the economic shocks that lead to changes in prices and quantities. This parametric approach to capture the disruption in the industry can estimate shocks within the demand and supply structures of the model, without relying on econometric assumptions. The model is established with elasticities and industry cost share data so that the results are consequently sensitive according to the elasticity values. In addition, the elasticity of substitution is crucial for absorbing the shocks of the industry, there seem to be demands for further studies on the empirical estimation of elasticity that identifies the substitution relationship between agricultural commodities used in food production. The ERM developed in this study for the US food sector can be extended to other industries to assess the welfare consequences of economic shocks or to demonstrate the relationship between other economic variables and changes in the industry's price and quantity.

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CHAPTER IV

CONCLUSION

This research attempted to the extent of the conventional EDM approach, which is still widely used recently to evaluate exogenous shocks such as government regulations, natural disasters, and market power determination. The first study estimated the magnitude of the effects of the CFAP payments in the US food industry. Using a model that links the production of 24 agricultural products with nine retail food categories, the effects of the financial assistance to producers and consumers in the US food industry were demonstrated. Findings address the relationship between the benefits of CFAP payments for agricultural producers and the possibility of substitution. The assumption of Leontief and CES production techniques are used to demonstrate the effect of the substitutability. If agricultural products for food production can be substituted for each other, producers maximize benefits by increasing the supply of commodities that are favorable to their revenue. As a result, as changes in the supply of agricultural commodities affect food prices, consumer benefits are transferred to producers, and producer’s benefits increase. The more substitutability is allowed between agricultural commodities for food production, the greater the benefit of the producer than the consumer, as the effect of the payments is absorbed by agricultural producers related to food processing. The result implies that the flexibility of the agricultural market that can be substituted between commodities allows the assistance paid to producers to be more attributed to producers’ benefits and improves the overall social welfare by increasing the benefits of producers.

The second study developed a parametric ERM to quantify the sector-specific shocks driving changes in prices and quantities in the US food industry and evaluate the changes in social welfare for each segment using a model that links the agricultural commodities with retail food markets. Under the different production technologies, the relationship between substitutability between agricultural commodities and economic shocks was addressed by comparing the Leontief model and nested CES model. The result revealed that the food industry can tolerate more economic shocks if technological substitution between agricultural commodities used in food production is possible. Estimating shocks were used to determine the effect of macro-economic indexes and the consequent social welfare change in the US food industry. This parametric approach to capture the disruption in the industry can estimate shocks within the demand and supply structures of the model, without relying on econometric assumptions. This study could contribute to the literature in that it presents a methodology for estimating the effects of inflation leading to price and quantity changes in the US food industry.

VITA

Miyeon Son

Candidate for the Degree of

Doctor of Philosophy

Dissertation: EXTENTION OF AN EQUILIBRIUM DISPLACEMENT MODEL: RELAXING THE FIXED PROPORTION ASSUMPTION AND RECOVERY OF SHOCKS UNDER OBSERVED EQUILIBRIUM

Major Field: Agricultural Economics

Minor: Statistics

Biographical:

Education:

Completed the requirements for the Doctor of Philosophy in Agricultural Economics at Oklahoma State University, Stillwater, Oklahoma in July, 2022.

Completed the requirements for the Master of Science in Economics at Kyungpook National University, Daegu, South Korea in 2010.

Completed the requirements for the Bachelor of Arts in Economics at Kyungpook National University, Daegu, South Korea in 2008.

Experience:

Research Assistant, Oklahoma State University 2018 to 2022

Teaching Assistant, Oklahoma State University 2021

Researcher, Department of Agricultural Outlook, Korea Rural Economic Institute (KREI), Naju, South Korea, 2013-2018

Researcher, Nuclear Training & Education Center, Korea Atomic Energy Research Institute, Daejeon, South Korea (KAERI), 2009-2013

Professional Memberships:

Agricultural and Applied Economics Association 2019-present

Southern Agricultural Economics Association 2019-present