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Modeling the US Beef Industry's Response to COVID-19

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Abstract

To understand the beef industry's response to the COVID-19 pandemic, I proposed a three-sector model of the beef supply-chain and estimated it econometrically. Based on their definitions, it is found that panic, stay-at-home procedures, and expectations are not significant explanatory variables. However, there is strong evidence that COVID-19 spread in a set of counties with large meatpacking plants has the effect of increasing wholesale beef prices, while country-wide spread has the effect of reducing wholesale prices. The results further imply differences in competition across the market levels, with wholesalers responding as if they face less competition than retailers and farmers.

Keywords

Supply-chain, Food marketing, Pandemic, Derived Relations, Price analysis

Cover Page Footnote

I extend my thanks to Professor Hans Czap for his guidance in completing this paper.

INTRODUCTION

On January 21, 2020, the United States confirmed its first case of SARS-CoV-2, more commonly known as the coronavirus or COVID-19. As case counts exploded both in the United States and worldwide, state governments across the country began to enforce mandatory shutdowns, which brought economic activity to a standstill and fueled panic-buying behavior in a variety of sectors, most famously in the toilet-paper market. As COVID-19 began to spread like wildfire through crowded meatpacking plants, causing plant shutdowns and widespread supply-chain disruptions, panic buying behavior became prevalent in retail beef markets too. These disruptions were exacerbated by stay-at-home procedures, which only put further pressure on retail grocers. Ultimately, meatpacking plant closures became so widespread that on April 28th, President Donald Trump signed executive order no. 13917 (2020), which required that meat and poultry processing plants continue operations amidst the pandemic so as to prevent massive beef shortages. Despite these efforts, wholesale beef prices soared, cattle prices fell, and consumers began to worry about whether or not the food supply-chain would be able to continue bringing meat to retailers and to their tables. As time passed, and producers acclimated to the additional difficulties associated with bringing meat products to market, price spreads slowly dropped from their previously record heights to more reasonable levels, and consumer panic has, for the most part, eased.

In 2019, Americans consumed 52 pounds of beef per person (USDA, 2020). To keep up with American's love for beef, the beef supply-chain operates a well-oiled machine that transforms live cattle into billions of pounds of processed cuts of meat in an incredibly cost-efficient manner. There is a great deal of research, both theoretical and empirical, that seeks to understand the mechanics of the beef sector as well as the sector's response to a number of economic shocks. As such, the COVID-19 pandemic presents a unique opportunity for researchers to precisely assess the impacts of massive stress on the beef industry, taking into account the industry's mechanics and organization. Ultimately, this paper will add to the ongoing discussions on the beef industry's structure by presenting novel research regarding the beef market's response to the pandemic. Moreover, the methods used in this paper will make an effort to quantitatively assess the specific effects of COVID-19 on prices in the beef supply chain. To perform this analysis, this paper will first review the literature that is relevant to agricultural supply-chains and the beef supply-chain in general, making a distinction between theoretical and empirical research. Then, I propose a structural model of the beef supply-chain that is specific to the COVID-19 pandemic. The model's mechanics will be demonstrated graphically and then econometrically estimated with data from the COVID-19 pandemic. I will then discuss the implications of these results, taking into consideration the market structures of each sector of the supply-chain.

Theoretical Approaches

The vast amount of research in the theory that backs agricultural supply-chain-modeling is extremely diverse and carries a wide range of applications for understanding the mechanics of a particular agricultural sector, such as the beef industry. However, given the unprecedented impact that COVID-19 had on the beef supply-chain, most, if not all prior research and existing models of agricultural supply-chains are unfortunately lacking in their ability to account for such an unprecedented shock. This is not to say there is no merit in this prior research; many of the modeling approaches that have been employed in the past have highly relevant components that will be necessary for understanding the beef sector in the midst of COVID-19.

The most traditional and arguably most practical economic models of agricultural supply chains are simply well-defined systems, or linkages, of supply and demand functions. Despite the prevalence and popularity of game theoretic approaches in the modern supply-chain literature (Bajgiran et al., 2019; Jang et al., 2011), the supply-demand framework is still incredibly useful and quite simple to apply to a variety of agricultural supply-chains. And, the model allows for the analysis of fundamental market relationships such as those between price and quantity. In a simple food supply-chain consisting of farmers and retailers, this particular modeling framework would involve the specification of only four functions: one for retail demand, another retail supply (or production), and the final two identify farm demand and farm supply. The "linkage" in this model is the retail grocer who is the agent who demands farm output. As will be shown, this simple two-equation-per-sector methodology can be heavily modified to fit the specifics of a certain industry.

Specifying which relations are primary and which are derived (Brester et al., 2004) is essential if one is to ensure a proper analysis. In agricultural supply-chains, it is generally understood that retail demand and farm supply are primary relations; that is, the functions can only be shifted by exogenous variables. All other supply and demand functions are considered derived, meaning the relationships are determined partially by endogenous variables in a different market level. These specifications of primary versus derived are important in models involving a graphical representation (Brester et al., 2004), as well as in models offering econometric estimation (Wohlgenant, 1983; Brester & Marsh, 1983; Marsh, 2003).

In building the actual model, one must consider the assumptions of the model as well as its overall purpose. For instance, Wohlgenant's model specifies only two sectors, farm and retail, so as to easily apply the model's conclusions to a variety of food value-chains (1989). Gardner's model specifies three sectors: the retail sector, and one sector for each of the factor inputs in the production of a certain retail food product (1975). Many models of the beef supply-chain, such as

Brester, Marsh, and Atwood's, as well as Tonsor's and Schroeder's, specify four sectors: retail, wholesale, slaughter cattle, and feeder cattle. Modles that are similar in terms of their sectoral specifications can still vary in terms of their actual model construction. Authors may, for instance, employ a production function in lieu of a price-dependent supply function. Or, they may make use of inverse demand and supply functions rather than "standard" functions in which quantity is determined by price. Finally, some authors relax the assumption of perfect competition, allowing for a more profound analysis of price transmission and market power in a supply-chain (Lloyd et al., 2000). In any case, these variations are indeed quite useful, and are possible due to the versatile nature of these sorts of models.

Once constructed, supply-chain models are often examined in the context of economic shocks. In the supply-demand modeling framework, authors will account for these shocks by attaching to a particular function a variable that is often called an exogenous "shifter." Depending on the purpose of the model, this variable can be labor costs, packing costs, or feed costs, among other possibilities. If an econometric analysis is to be performed, such as in work by Wohlgenant (1989), Brester & Marsh (1983), and Dunn & Heien (1985), the shifter variable is broken into smaller components that are relevant for the analysis. Purely theoretic models such as Muth's (1964) or Gardner's (1975) rarely, if ever separate an exogenous shifter in this way. In these cases, the exogenous variable is left as is in order to represent any shock at all to the system. Doing this is effective for model simplification but can tarnish predictive power when attempting to distinguish between the effects of particular shocks.

One important assumption which is often debated in the modeling of an agricultural supply-chain is that of fixed versus variable input proportions. Variable input proportions, a case where the elasticity of substitution is nonzero, is the leading assumption in most modern frameworks. Although earlier modeling strategies did assume fixed proportions, Gardner (1975) argued that these assumptions do not hold, and Wohlgenant (1989) presented empirical evidence to corroborate. The primary consequence of assuming variable input proportions is that it allows output to vary along market levels (Tonsor & Schroeder, 2015). This is useful since it more accurately represents the true nature of a supply-chain, allowing agents to substitute between inputs of production based on relative price changes. With that said, in graphical analyses, fixed input proportions are often assumed to simplify the analysis (Brester et al., 2004). In addition, fixed proportions may be assumed when data on a certain market level are not available, as it allows for a simple calculation of derived elasticities at these levels (Asche et al., 1999).

Generally, structural supply-chain models are manipulated in order to perform further empirical or theoretical analysis. Wohlgenant's (1989) model employs an equilibrium constraint to effectively eliminate all quantity variables from the model, allowing for ease of estimation given lack of certain data. Gardner's (1975) model performs mathematical manipulations inspired by Muth (1964) which allow for a theoretical derivation of the factors determining the farm-retail price spread. Although the model presented by Gardner considers a relatively simple supply-chain, Xiao (2010) later enhances the framework to consider more complex cases. One particular manipulation that is quite powerful in beef economics is the equilibrium displacement model (EDM). An EDM is achieved by totally log-differentiating the supply and demand functions so as to convert the functions to elasticity form. With this manipulation, researchers may estimate the welfare impacts of an economic shock. The EDM is particularly useful in that it allows for calculations of consumer and producer surplus along a supply-chain so as to define not only total welfare change, but the actual distribution of benefits and costs (Brester et al., 2004).

Although the approach of an EDM is appealing in that it allows for powerful quantitative estimation under various market scenarios, the approach requires elasticity estimates which are subject to market forces, especially in a severe economic shock. As such, in-depth EDM analysis of the beef sector must follow more preliminary research which establishes a potential modeling solution for the beef sector's response to COVID-19. Given the usefulness of the traditional supply-demand framework, the construction and mechanics of the models previously discussed will be important inspiration for models going forward. This, along with an empirical toolkit for estimating these models, will allow for highly predictive, versatile models like the EDM to one day present reasonable conclusions.

EMPIRICAL APPROACHES

The novel coronavirus (COVID-19) pandemic, although certainly unprecedented, is not the first time that the beef industry has undergone stress. As such, there exists a large amount of empirical research which aims to understand shocks to the beef supply-chain, both in the United States and globally. To an extent, there is already a growing literature performing research specific to COVID-19. Although most of this research is observational, growing availability of data will allow for more interesting findings. Thus, reviewing the existing methods of empirically modeling shocks to the beef supply-chain will be an important precursor to quantifying the impact of COVID-19 on the beef sector. In addition, it may allow for a better understanding of where the beef industry may be headed in the long run, which will have important implications for cattle farmers, packers and beef consumers.

The beef industry has even been affected by outbreaks before. In the 1980s and 1990s, bovine spongiform encephalopathy (BSE) had a severe impact on beef and livestock markets in the United Kingdom. In fact, a recent article on the North American beef sector's response to COVID-19 points to some similarities between these two outbreaks in terms of their market responses, especially as it pertains to falling cattle prices and massive shifts in consumer behavior (Rude, 2020). Unlike COVID-19, the impacts of BSE on U.K. beef markets are well-documented and well-understood. McCorriston et al. (2001) employed a vector autoregression procedure in an effort to explain an 18% drop in retail prices and a 40% drop in wholesale and farm-level prices. Using a cointegration framework, the authors find that much of this movement was founded in media-induced consumer panic. By including a variable to account for food publicity in the media, the authors find that their model does a better job explaining price movements than it did without the publicity variable. Another paper on the BSE crisis uses similar techniques and reports the existence of a "structural break" in prices that occurs in the beef sector, but not in the pork or lamb sector (Sanjuan & Dawson, 2003). This particular research also provides empirical support for Gardner's (1975) theory by demonstrating that a decrease in retail demand caused the farm-retail price spread to fall.

In the U.S, there have been few severe short-term shocks to the beef sector, so the majority of empirical beef supply-chain research has sought to understand the mechanics of the beef sector over long time periods. In doing so, researchers make use of the theoretical frameworks described in the previous section, employing econometric techniques and available data to estimate relevant parameters defined by the models (Brester & Marsh, 1983; Marsh, 2003; Wohlgenant, 1989). Aside from ascertaining the effectiveness of the chosen theoretical model, the estimation allows for a better understanding of how economic shocks present themselves in relevant market variables. Wohlgenant (1989), for instance, finds an exogenous 1% increase in retail demand increases retail and farm prices by 0.64% and 1.35%, respectively. Marsh (2003) finds that a 1% increase in retail demand translates to a 0.60% increase in cattle prices. Brester & Marsh (1983) find that a $1 increase in the farm-to-carcass marketing margin, a function of exogenous variables such as wages and oil prices, depresses slaughter cattle prices by $0.43. Although each of these variables are found to be statistically significant, the statistical results of these same papers do reveal some insignificant variables. Interestingly, Wohlgenant's marketing cost variable is one of these, which is not only insignificant, but has slope estimates that differ from what theory, as well as Brester & Marsh's (1983) research, would predict. Whether this insignificance is due to the time frame of the analysis or the variable's operational definition is unclear.

There are a variety of commonalities that can be found in this empirical research. For one, due to the nature of available beef industry data, most authors assume constant elasticities when estimating structural supply or demand equations (Marsh, 2003). However, this practice, especially over longer time periods, has been called into question by more recent research demonstrating highly variable elasticities along a beef demand curve (Lusk & Tonsor, 2016). Another common tool used in empirical supply-chain research is estimation by instrumental variables, an econometric method employed when there is speculation of a joint dependency in the system of supply-demand equations. Brester and Marsh (1983), for instance, estimate the marketing margin as a function of wages and oil costs, then substitute the predicted values obtained from this estimation into their equation for supply. This procedure helps to eliminate bias in the slope parameters that arise from joint dependencies, and allow for a better-fitting econometric model.

Although there are some similarities in the econometric techniques employed in these papers, each author ultimately uses a unique statistical approach corresponding to the specific questions that the research poses. A particularly unique technique in the econometric modeling of livestock production is the distributed lag framework, which allows for an empirical estimation of the effect of shocks in both the short and the long run. When it can be speculated that certain variables in the model are partially influenced by prior values (higher cattle price in year t-1 leads to greater cattle supply in year t), a lag framework can be utilized to exploit these time-dependencies and ultimately estimate the effects of shocks on market variables over short and long periods of time (Brester & Marsh, 1983). Another unique statistical method is one in which econometric models are constrained by assumptions such as fixed input proportions or constant returns to scale and then subsequently estimated with relevant data. Wohlegnant (1989) used this method to provide empirical support for the assumption of variable input proportions by comparing parameters in the non-constrained model to those in the constrained one. While these unique statistical approaches do allow for interesting and useful results, they are all ultimately founded in the classical ordinary least squares regression procedure, which, if properly specified, may allow for an effective analysis of a beef supply-chain on its own.

Current research on COVID-19 has been largely focused on simply reporting data and presenting potential theoretical explanations (USDA, 2020; Martinez, Maples, & Benavidez, 2020; Hobbs, 2020). That is, there is little causal inference being drawn, even when modeling efforts are employed. For instance, Rude (2020) uses an econometric simulation model to forecast retail prices, steer prices, and industry revenue in light of COVID-19. The model ultimately highlights the importance of income in determining future industry revenue. However, Rude notes that the model does not account well for panic buying, which is especially troubling since some supply-chain disruptions were partially fueled by large, panic-driven increases in demand. Other research has been focused on concerns over higher price spreads in the beef marketing chain and implications for the future of the beef industry's organization (Lusk et al., 2020). The authors use a variety of theoretical approaches to explain the higher price spread and ultimately show that margin estimates are highly sensitive to the procedures used to calculate them.

Finally, there has been some research that points to the exposure of the beef sector to COVID-19 given working conditions in packing plants (Saitone et al., 2020). The authors of the study show that counties with meatpacking operations experienced an 800% greater case count than counties without plants. Unfortunately, given the lag time in the dissemination of quality, detailed data, there is no research at the time of this writing related to the specific, quantifiable effects of the virus and associated panic behavior on prices throughout the supply-chain. The purpose of this paper is to fill that gap.

STRUCTURAL MODEL

The structural model of the beef supply-chain proposed in this paper is inspired by Wohlgenant's (1989) two-sector model for a farm-to-retail supply-chain. Wohlgenant's model is extended to a three-sector approach and given parameters which allow for an analysis specific to the COVID-19 pandemic. The three sectors identified by the model can be described by the following system of nine equations, which are described in detail below.

(1) Retail demand (primary): $Q_r^d = f(P^r, W)$
(2) Retail supply (derived): $Q_r^s = \sum f(P^r, P^w, X)$
(3) Equilibrium: $Q_r^d = Q_r^s$

(4) Wholesale demand (derived): $Q_w^d = \sum f(P^w, P^r, X)$
(5) Wholesale supply (derived): $Q_w^s = \sum f(P^w, P^f, Y)$
(6) Equilibrium: $Q_w^d = Q_w^s$

(7) Farm demand (derived): $Q_f^d = \sum f(P^f, P^w, Y)$
(8) Farm supply (primary): $Q_f^s = \sum f(P^f, Z)$
(9) Equilibrium: $Q_f^d = Q_f^s$

RETAIL SECTOR

Retail demand is a primary relationship, where retail quantity demanded (Q_r^d) is a function of the price of retail beef (P^r) and an exogenous demand shifter called W. In the context of COVID-19, the demand shifter could be expressed functionally as $W = f(S, P)$where S represents retail demand shifted by stay-at-home protocols and P represents panic-driven demand changes. This function indicates that the exogenous shifters of demand are either stay-at-home protocols or panic. Thus, it may be convenient to rewrite primary retail demand as $Q_r^d = f(P^r, S, P)$.

Retail quantity supplied (Q_r^s) is expressed as the summation of each individual retailer's supply function. From this point forward, each supply and demand function in the model will be expressed in this way to be careful about the distinction between market supply and the individual firm supply. Retail supply is ultimately a function of retail price (P^r) and the wholesale price of beef (P^w). Since P^w represents an input price in the production of retail beef, this further highlights the theoretical convenience of using the summation notation. Namely, each individual firm sees P^w as a cost, and therefore will wish to reduce quantity supplied at higher levels of P^w and increase quantity supplied at lower levels. Since we are using a summation, the effect of these wholesale price changes is seen as a shift in the total market supply function. And, due to this relationship between retail quantity supplied and the wholesale price, retail supply is a derived relationship. Retail supply is also a function of a supply-shifter X which could be thought of as a variable representing costs arising from sanitation measures and other CDC-mandated protocols related to COVID-19.

Wholesale Sector

The wholesale sector encompasses the activities of slaughtering cattle and packing beef which is then purchased by grocers and other retailers. In other words, wholesale beef is demanded by the retail suppliers. Wholesale demand is a function of the price of wholesale beef (P^w) and the price of retail beef (P^r). As retail prices rise, an individual retailer will demand more wholesale beef to take advantage of higher profit margins, making this relationship a derived one as well. Again, the summation notation makes it clear how these price changes affect total market supply. Wholesale demand is also a function of the shifter X, which is the same shifter that is a determinant of retail supply. These shifters are identical because adverse shocks to retail supply via a change in the variable X will have a similarly adverse effect on the wholesale demand function, being that retailers are the demanders of wholesale products. In other words, changes in X result in equal shifts (in the same direction) to retail supply and wholesale demand. Wholesale supply has similar mechanics to retail supply in that it is determined by same-level market prices, wholesale prices and prices one market-level below, farm level prices (P^r), which are an input in wholesale production. Wholesale supply is also determined by a shifter Y which represent supply-shocks driven by COVID-related disruption to packing and slaughtering beef.

FARM SECTOR

The farm sector includes all activities related to nurturing and feeding cattle until they are ready for slaughter, at which point the cattle would be purchased by packers and processors. Farm demand is a function of farm price (P^f) and wholesale price (P^w). As wholesale prices rise, the individual processor will realize higher profits and therefore will demand more cattle. Similarly, as before, farm demand is a function of a shifter Y. As wholesalers experience economic shocks via changes in the variable Y, they will adjust their cattle demand accordingly, making farm demand also a function of this shifter. Farm supply is a primary relationship and is determined solely by the farm price and a shifter Z.This shifter may represent voluntary reductions in supply due to low current farm prices and expectations for higher prices in the future.

SHOCKS

The shocks that COVID-19 presented to the beef supply-chain are given by the four shifters $W(S,P)$, X, Y, and Z, which are specified above in relation to their relevant functions. The COVID-19 crisis had direct and indirect impacts on each of these variables primarily over a two-month period between March 2020 and May 2020. In early to mid-March, the pandemic brought-about school closures, businesses shifting to remote work, and restaurants no longer able to offer in-person dining. As a result of these changes, food service demand fell, and retail demand rose, represented by a change in W through a change in S. In addition, retailers at this time were facing slightly higher costs as a result of various measures that were being taken to prevent the spread of the virus. These cost-driven shifts are represented in X and shifts both retail supply and the demand for wholesale beef.

Beginning in April, meatpackers began to experience severe disruptions in their operations due to an increasing number of cases in their plants. These increases in cases were likely driven by working conditions in the plants as well as the demographic composition of the plant employees (Saitone et al., 2020). These changes are large and are represented by changes in Y and affect both the supply of wholesale beef and the demand for cattle. Following these plant shutdowns and the resulting increases in the price of beef, consumers feared that prices would rise even further, which caused a further surge in demand through a change in W due a change in P. Finally, it should be recognized that changes in the variable Z (on farm supply) are present but quite difficult to identify. The variable likely had its largest impact in late April to early May as some cattle farmers responded to the very low current prices and expectations for high future prices by holding their stock until the prices rose.

GRAPHICAL ANALYSIS AND WELFARE IMPACTS

The graphical analysis will be done in three phases. Phase I covers the period of time beginning in early to mid-March. Phase II represents the period of time beginning in mid to late April, and phase III will represent the time shortly after, when consumers began to react to the events of phase II. Each graph assumes fixed input proportions, which allows for a simplification of the analysis. In this case, fixed input proportions means that output is equal across all market levels; in other words, one unit of retail beef represents some fixed percentage of a unit of cattle. It is also assumed that all elasticities of demand and supply are approximately equal across all market levels. This assumption makes little difference in terms of the absolute analysis of prices but does hinder our ability to understand relative price changes and thus price spreads. However, allowing for different elasticities at different marketing levels would greatly overcomplicate the analysis. Further, the analysis could be rendered void by the possible variation in elasticities caused by the pandemic, justifying the simplifying assumption as a means for a more general and applicable analysis.

I. *Phase I*: In the early stages of the pandemic, retail demand was shifted to the right by stay-at-home protocols, putting upward pressure on retail prices, and hence increasing wholesale demand. At the same time, there were cost-driven adverse shifts in supply which are assumed to be smaller in magnitude than the shifts in retail demand. The theoretical result is rising prices in both sectors ($P^r \rightarrow P^{r\prime}, P^w \rightarrow P^{w\prime}$) and a higher overall quantity of beef ($Q \rightarrow Q'$). In this analysis, we can see that retail prices rise slightly more than wholesale prices, increasing the wholesale to retail price spread ($P^r - P^w$). Of course, this assumes that retail demand was shifted more than retail supply, a reasonable assumption given the severity of the demand-shift that occurred in the early stages of the pandemic. Empirical estimation will determine the true effect of these exogenous shocks. In terms of welfare, both consumers and producers of wholesale and retail beef were economically better off in the early stages of the pandemic. Producers of retail beef are better off since the market price rose faster than increases in marginal cost, indicating a higher producer surplus. Producers of wholesale beef were better off since there is a higher wholesale price and greater output. Consumers are better off in both the retail and wholesale markets since there is a higher quantity of output, and the increase in the price of beef does not exceed the increase in consumer's willingness to pay for beef - the result is a higher surplus. Again, the assumption of retail supply having a smaller shift than retail demand is crucial for these results. These effects are illustrated in figure I.

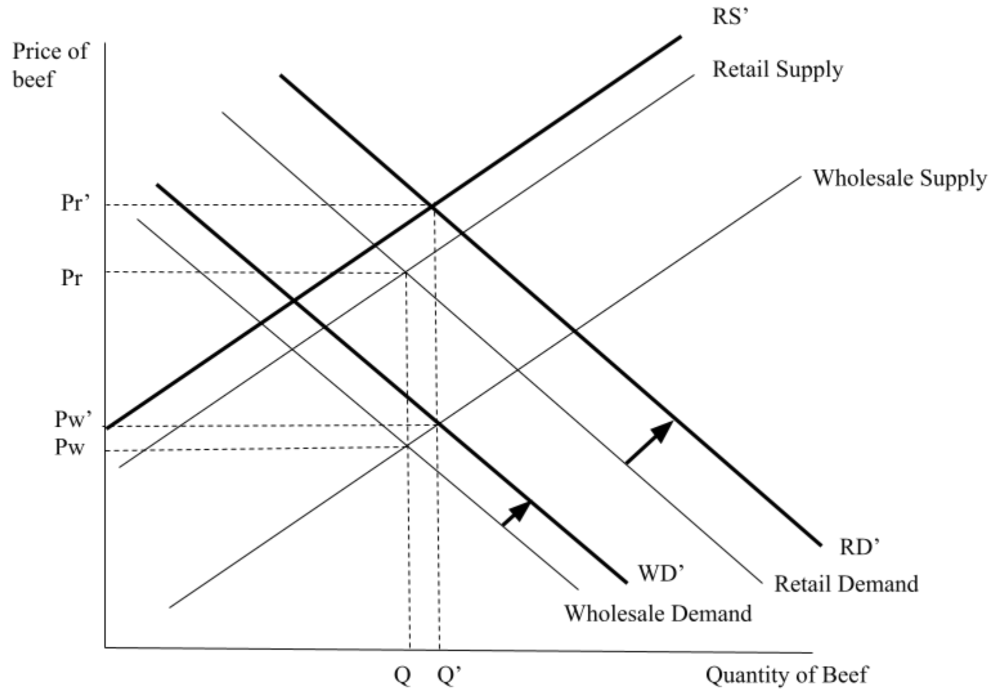

Fig. 1 - Phase I

II. *Phase II.* As the pandemic raged on, shutdowns in meatpacking plants due to a high number of COVID-19 cases caused a massive reduction in wholesale supply with a coupled decrease in farm demand. Despite President Trump's April 28th executive order no. 13917 (2020) requiring that meat processors continue to operate amidst rising COVID-19 cases, wholesale supply likely remained restricted for an extended period due to high operating costs and other COVID-19-related disruptions in production. The result of this adverse shock was a lower market quantity ($Q \rightarrow Q'$), higher wholesale prices, lower cattle (farm) prices ($P^w \rightarrow P^{w'}, P^f \rightarrow P^{f'}$), and consequently a much-higher farm-to-wholesale price spread ($P^{w'} - P^{f'}$). In terms of welfare, consumers and producers of wholesale beef and cattle were, in aggregate, both worse off as the pandemic reached its heights in stage II. Wholesale consumers (retailers) experienced producer surplus reductions due to high prices and low quantities. Wholesale suppliers, in aggregate, experienced marginal costs rising faster than prices, and thus total surplus reductions on the supply and demand side. Although there are surplus reductions in aggregate, it can be argued that the individual wholesale processor may have been better off: input costs were falling while output prices rose (rising price spread). Further, although surplus fell, there were a smaller number of firms fighting over this surplus (due to closures), implying a potential for higher per-firm surplus.

While this observation has merit, each individual firm produces less output at Q' than at Q. Further, as noted by other researchers, if it were truly in a firm's interest to reduce supply to make themselves better-off, they could have reduced capacity prior to COVID-19, which they did not (Lusk et al., 2020). The welfare analysis for cattle farmers (farm suppliers) is relatively simple: lower prices and falling output made them worse-off. Figure 2 depicts these events. It should also be mentioned that there may or may not have been a leftward shift in retail supply (due to Z) because of an expectation for eventual higher future prices. However, it is not included in the illustration since the effects of this shift were relatively small compared to the shifts in wholesale supply. Further, the results of the analysis

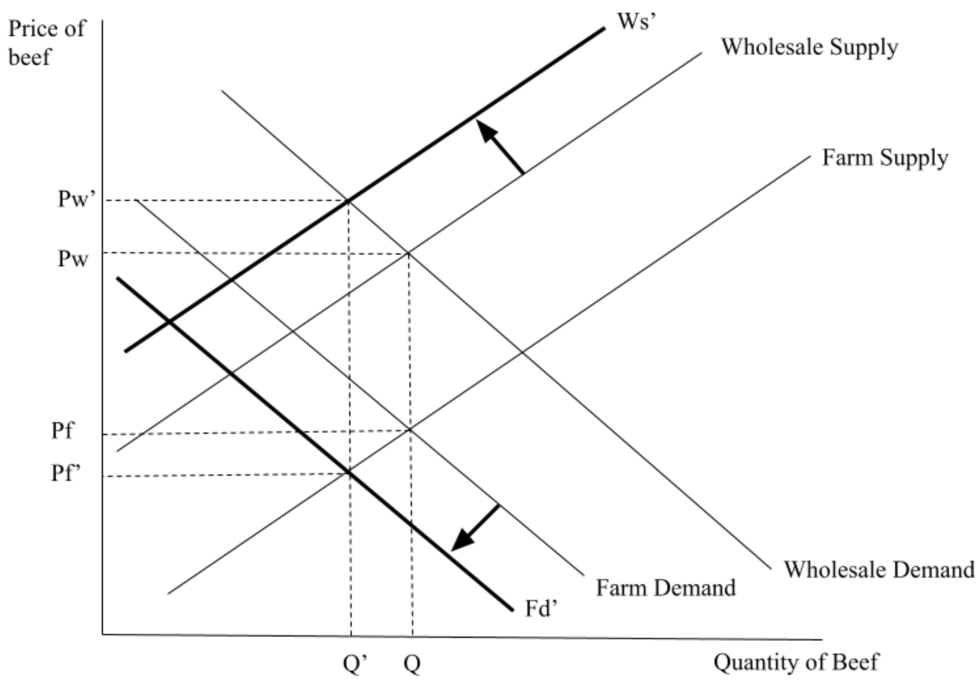

Fig. 2 - Phase II

change only minorly, quantity would fall further, and prices would rise in both the farm and wholesale sector.

III. *Phase III*. This is the most complex phase since it includes a spillover event from phase II. Namely, the adverse shock to wholesale supply from phase II is also depicted in the illustration along with the purely phase III events (figure 3). Higher wholesale prices resulting from the adverse shock cause an additional adverse shock to the retail supply curve, shifting it upward and to the left. The equilibrium here after this shift is at $P^{r\prime}$ and Q'. Clearly, this adverse shock to the wholesale market resulted in higher retail prices. Phase III begins when consumers react to this price increase and the possibility of additional price increases, shifting retail demand to the right and putting further upward pressure on the retail price. With the shift in retail demand, the model indicates that wholesale demand must shift as well, putting further upward pressure on the wholesale price. In terms of welfare, the adverse supply shock to retail supply made retail suppliers and consumers worse off. The shift in retail demand technically made consumers better off, but it is strange to interpret this as such since the shift only further served to stress the beef supply-chain. Figure III graphically illustrates these events.

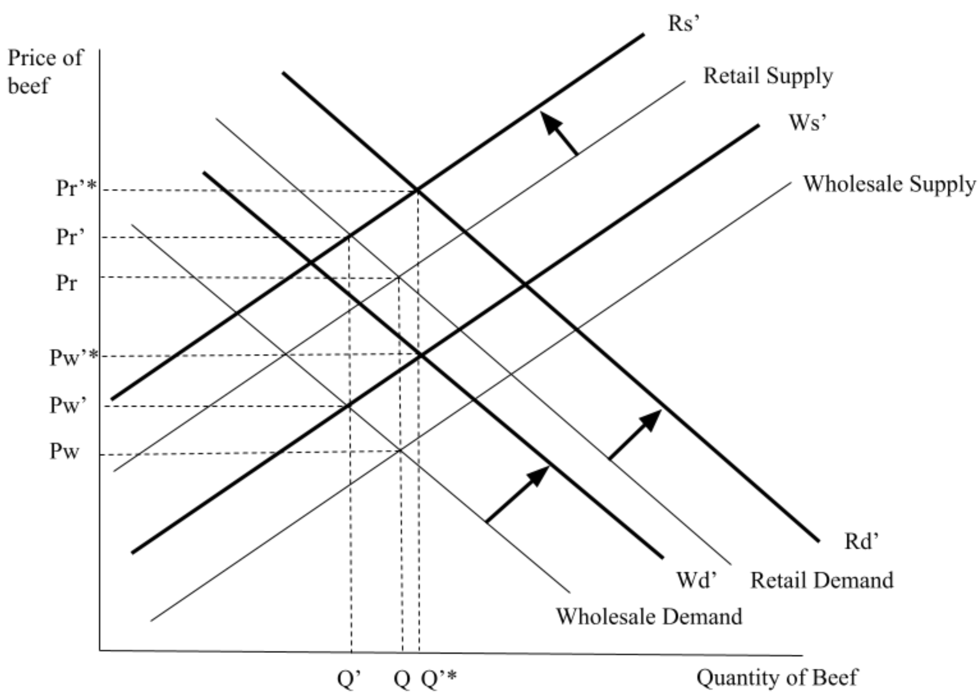

Fig. 3 - Phase III

ESTIMATION

Before the structural model can be estimated with relevant data, I will perform a manipulation to prepare the model. By applying the equilibrium constraint to the model, we have:

$$\text{Retail sector: } \sum f(P^r, P^w, S, P) = f(P^r, X)$$
$$\text{Wholesale sector: } \sum f(P^w, P^f, Y) = \sum f(P^w, P^r, X)$$
$$\text{Farm sector: } \sum f(P^f, Z) = \sum f(P^f, P^w, Y)$$

This equilibrium constraint is convenient since it allows us to remove all quantity variables from the equation. Further, it is possible to see that the functions can be rearranged so that the left-hand side of each equation is the price of that market level. Wohlgenant's (1989) model describes the specifics of log-differentiating each system to show the actual elasticities of each variable - we refer the interested reader to their paper. Following their derivation, the new model can be written as:

(10) Retail sector: $P^r = f(P^w, S, P, X)$
(11) Wholesale sector: $P^w = f(P^r, P^f, X, Y)$
(12) Farm sector: $P^f = f(P^w, Y, Z)$

All else equal, the retail price theoretically depends positively on the wholesale price, positively on S and P, and positively on X. The wholesale price depends positively on the retail price, positively on the farm price, negatively on X, and positively on Y. Finally, the farm price depends positively on the wholesale price, negatively on Y, and positively on Z. This summarizes the model. From here, we proceed by identifying relevant data for the model, and econometrically estimating the functions to quantify the specific effect of COVID-19 on prices in the beef supply-chain.

DATA

The variables that will be measured for the econometric analysis are the retail price P^r, the retail demand shifters (stay-at-home and panic) S and P, the retail supply shifter (and, identically, the wholesale demand shifter) X, the wholesale price P^w, the wholesale supply shifter (farm demand shifter) Y, the farm price P^f, and the farm supply shifter Z. This section will explain the operational definition of each variable in the econometric model as well as the data employed for its measurement. We will use these data, which are weekly and span over the time period from March 13th, 2020 to October 2nd 2020, to estimate the structural model that was introduced in the last section.

The endogenous price variables for the retail, wholesale, and farm sectors are all measured, recorded, and made publicly available by the USDA's Agricultural Marketing Service (2020), the units for these variables being dollars per hundred pounds of beef. The retail price of beef is represented by a ground beef price index, which is a function of advertised retail ground beef prices in a given week. Ground beef, among other cuts of beef, was chosen to be the focus of the analysis due to its heightened popularity amidst the pandemic. This popularity means it may have been particularly responsive to panic buying and stay-at-home orders. The price index was constructed by averaging the prices of ground chuck, sirloin, round, 90% or more ground beef, 80-89% ground beef, 70-79% ground beef, and beef patties for a given week during the pandemic. Therefore, the variable is essentially the weekly average price of ground beef. The wholesale beef price is measured as the weekly average choice beef cutout, which is the weighted average value of a beef carcass after leaving a processor. The farm price is measured as the value of a steer as it leaves the feedlot: it is the average price paid in a given week for fed cattle.

The retail demand shifter has two components. The first component, the stay-at-home factor, is measured as the percent of the continental United States population that is under a statewide, mandatory lockdown. Higher values for this variable should correspond to higher retail beef prices. The data for this variable are obtained from a CDC publication which compared state's responses to the virus (Moreland et al., 2020). The second component of the retail demand shifter is the panic factor, which is measured using Google Trends data on the search term "beef shortage" with a two-week lag. That is, we expect beef prices in a given week to be related to the relative Google search interest for "beef shortage" two weeks prior. Implementing this lag allows us to account for the friction that exists in price adjustment; the lag corresponds to the time it may take retailers to adjust prices given demand changes as well as the time it takes consumers to change their purchasing behavior following exposure to panic-inducing media. Overall, a higher value of the panic variable should coincide with higher beef prices in the following weeks.

The retail supply shifter (and thus wholesale demand shifter) is measured as the percent of the United States population that contracted COVID-19 in a given week (based only on confirmed cases). This variable uses data from the Johns Hopkins Coronavirus Resource Center (2020) and is calculated by summing daily COVID-19 cases over a week (or subtracting total cases at the beginning of the week from the total cases at the end of the week), and then dividing by the United States population. The entire United States was used as the population base for this analysis due to the fact that COVID-19 had the nationwide effect of raising costs for retailers. These increased costs, as this model hypothesizes, will be directly related to the percentage of the population that contracts COVID-19, and thus these rates of infection will be directly related to the retail price.

The wholesale supply shifter (and farm demand shifter) is measured in a similar fashion to the retail supply shifter and uses data from the same source. However, rather than looking at the entire United States population, the wholesale supply shifter considers only the population of eleven counties that contain a large (as defined by the USDA) meatpacking plant owned by one of the two largest United States beef packers: Tyson Fresh Meats or Cargill Meat Solutions. These specific counties were found using the USDA's Food Safety and Inspection Service packing plant database (2020), and their infection rates were obtained using the same data from Johns Hopkins (2020). Aside from the change in the population base, the wholesale supply shifter variable is computed in the same way as the retail supply shifter: it is the percent of the population in these sample counties that contract COVID-19 in a given week.

The final variable, the farm supply shifter, is represented by the October 2020 futures price for live cattle, as quoted by the Chicago Mercantile Exchange (Barchart, 2020). This futures price reflects the market's expectations regarding the October 2020 price of a fed steer. Thus, as the price on a futures contract rises, it is expected that some cattle farmers will forgo putting their steer to market, taking on larger costs to feed their stock in hopes of earning a higher profit when the price rises, and therefore causing the farm price to rise now. Anecdotal evidence from the pandemic suggests that these choices may have been particularly attractive to farmers since feed costs in mid-2020 were quite low, and current cattle prices were very low. In the next section, these data will be employed to econometrically estimate the proposed structural model.

RESULTS

The following tables 1-3 present the regression outputs for the retail (defined by ground beef prices), wholesale, and farm sectors. The model was estimated in log-log form for the price variables and log-lin form for the non-price variables. The log-log form was used to evaluate relevant elasticities, but the log-log form could not be used on the non-price variables due to the fact that some observations were zero. Below, the models are reviewed for signs of violations to the classical linear regression model assumptions, and the necessary corrective steps are discussed.

Table 1: Regression Results

Dependent Variable	$\ln(P^r)$	$\ln(P^w)$	$\ln(P^f)$
Intercept	5.28***	-9.70***	3.52
P	0.0013		
S	0.027		
X	32.46	-126.60**	
$\ln(P^r)$		1.48***	
$\ln(P^f)$		1.34***	
$\ln(P^w)$	0.13**		0.21**

Y		103.56***	-25.13
Z			-7.3E-06
R-squared	0.46	0.85	0.39
F	74.12***	41.79***	2.54*

***—significant at 1%, **—significant at 5%, *—significant at 10% (two tailed)

The preliminary regression on the retail sector $\ln(P^r)$ displayed signs of autocorrelation. To correct for this, the regression was redone with an HAC procedure, and the regression output above reflects the new output. The regression on the wholesale sector $\ln(P^w)$ displayed signs of heteroscedasticity and autocorrelation, as well as evidence that the relationships may be nonlinear. Various different functional forms were attempted in an effort to correct the nonlinearity, none except a regression on $1/P^w$ resulted in a better model fit, and even this specification only returned slightly better model fit, and still displayed nonlinearity. The results of the regression on $1/P^w$ are available in the appendix, but for interpretation purposes the regression on $\ln(P^w)$ will be evaluated, and was corrected with an HAC procedure. The regression model for the farm sector also suffers from autocorrelation and potential nonlinear relationships. As with the wholesale model, a regression on $1/P^f$ slightly improved the model fit, but not enough to completely correct the nonlinearity. The results of this regression are in the appendix. As for the interpretation, the log-log regression of the farm sector will be evaluated, with an HAC procedure employed to correct the autocorrelation. This details all corrective steps that were taken.

RETAIL SECTOR: ECONOMETRIC RESULTS

The retail sector's model appears to be working relatively well. The model appears to explain 46% of the variation in (log) retail ground beef prices, and this percentage is statistically highly significant. Each variable in the model has an estimated slope that is consistent with the theoretical framework. However, only the wholesale price has a slope that is statistically significantly different from zero (two-tailed). With that being said, there is moderate evidence that the panic variable has a positive slope (p-value/2 < 0.05, one-tailed). Therefore, there is strong evidence in support of the theoretical framework as it pertains to the effect of wholesale prices on retail prices, and moderate evidence as it pertains to the effect of panic on retail prices.

The estimated elasticity of price transmission from wholesale to retail prices is about 0.13. Meaning, for every 1% increase in the wholesale price, there is a 0.13% increase in the retail price, all else equal, on average. The estimated coefficient on the panic variable indicates a one unit increase in the relative search interest for beef shortages increases retail beef prices by 0.13%, on average, which is arguably negligible. The coefficient on the stay-at-home variable, 0.027, indicates that for each one percentage point increase in the percentage of the country on a statewide, mandatory stay-at-home order, there is a 2.70% increase in the price of retail ground beef per hundred pounds. The coefficient on the cost-related COVID-19 variable, 32.46, indicates that for each one percentage point increase in the weekly percentage of the United States that contracted COVID-19 (*confirmed cases only*), there is a 3,246% increase in the price of ground beef per hundred pounds. This is slightly misleading because a one-week, one percentage point increase in the percentage of the population contracting COVID-19 would be astronomical. It may be more telling to state that for each 0.01 percentage point increase in the weekly percentage of the population contracting COVID-19, the price of beef per hundred pounds would increase by about 32%. This is essentially the estimated impact of a leftward shift in retail supply due to greater COVID-19 rates of contraction.

WHOLESALE SECTOR: ECONOMETRIC RESULTS

The econometric model of the wholesale sector works very well, explaining about 85% of the variation in (log) wholesale prices. There is strong evidence that (log) retail prices, (log) farm prices, and local COVID-19 "spread rate" (or rate of contraction) are significant explanatory variables in explaining variation in wholesale prices. There is only moderate evidence that total spread rate is a significant predictor of the wholesale price. There is strong evidence in support of the theory as it pertains to the effect of retail prices, farm prices, and local spread rate on wholesale prices. There is moderate evidence in support of the theory as it pertains to the effect of total spread rate on wholesale prices.

The results indicate that wholesale prices are very sensitive to changes in retail and farm prices. The coefficients of 1.48 on retail prices and 1.34 on farm prices are far higher than what is observed for the retail and farm price sensitivity. The estimated coefficient on the cost-related COVID supply-shifter (total US spread rate), -126.60, indicates that for each 0.01 percentage point increase (about an additional 350,000 individuals in the United States) in the total confirmed weekly rate of contraction, the wholesale price of beef per hundred pounds decreases by 127%. This is the estimated price-impact of COVID-driven reductions in wholesale demand due to higher operations costs to retailers resulting from COVID-19 spread. Similarly, the estimated coefficient on the local rate of contraction (Y), 103.56, indicates that for each 0.01 percentage point increase in the percent of local population contracting COVID-19, there is a 103% increase in the price of wholesale beef per hundred pounds. This is the estimated impact of an adverse shift to wholesale supply due to local COVID-driven cost increases. It is important to note that although the coefficient for the total spread variable (which has a negative effect on wholesale prices) is larger in absolute terms, there were much larger increases in the local spread rate at the height of the pandemic, which explains why prices of wholesale beef rose, rather than fell.

FARM SECTOR: ECONOMETRIC RESULTS

The regression on the farm sector explains 39% of the variation in (log) cattle prices. There is only weak evidence that the variation explained in this model is statistically greater than zero. Both the wholesale price and the local spread rate (Y) have signs that are consistent with the theory, however only the wholesale price is significant. The expectations variable, which is the farm supply shifter, is found to be statistically insignificant, with a sign that is opposite of that predicted by the theory. The results show that farm prices are not very sensitive to changes in retail prices, a 1% increase in the wholesale price only increases farm prices by 0.21%. The estimated coefficient on the local spread rate, -25.13, indicates that for a 0.01 percentage point increase in the percentage of the local population contracting COVID-19 over a given week, the price of cattle per hundred pounds falls by about 25%. This is the estimated impact of a leftward shift in farm demand due to increased costs of operations resulting from local COVID spread rates.

DISCUSSION

The main takeaway from the econometric model is that, at the very least, it is consistent with the fundamental price transmission dynamics proposed by the theoretical framework. That is, all prices should trend in the same direction, and the models provide strong evidence in support of that idea. Unfortunately, however, a number of variables, specifically in the retail and farm sectors, are more or less insignificant. These variables are the stay-at-home variable, the panic variable, and the expectations variable. That is not to say these variables are meaningless. There is strong anecdotal evidence that stay-at-home procedures and panic very likely had a role in price variation in the beef supply chain, which implies that there is possibly a measurement error or an issue with the variable definitions. Additionally, there is some evidence from this estimation that panic is associated positively with beef prices (one-tailed), although the coefficient itself is not statistically significantly different from zero (two-tailed), so there is more work to be done on the effect of panic. Overall, aggregating shifts in preferences driven by stay-at-home procedures and panic across the entirety of the United States economy is very difficult, and it is likely inappropriate to use one single variable in measuring these changes in preferences. Expectations of cattle farmers may be the most difficult to measure of all three variables, since there is no good way to predict exactly what cattle farmers may have been thinking at a time of extreme stress, concerns about the bottom line, and concerns about the future of their industry. Perhaps the first step in studying the effect of futures prices on expectations should be to identify a proper lag time between the futures price and corresponding changes in cattle prices.

Regardless of the irrelevance of these variables, the COVID-contraction (spread rate) variables (X, Y), did have a significant role in explaining price variation in the wholesale sector. In general, the econometric model of the wholesale sector is very strong, implying that it may be easier to model sectors that are entirely based on derived relationships rather than those that are based on primary relationships. Primary relationships tend to have prices that are subject to random, difficult-to-predict fluctuations that are tough to measure and therefore tough to model (as mentioned, panic and expectations). The wholesale sector's prices do react to these changes, but only through changes in prices in other market levels, which make it much easier to model. Strangely, the results show that indeed greater total spread (X) depresses wholesale prices, likely through a decline in wholesale demand, but do not significantly indicate that greater spread increases retail prices through a shift in retail supply (although the slope is still consistent with the theory). Conversely, the model shows that greater local spread rate increases wholesale prices through a shift in wholesale supply but does not show significant evidence of local spread rate reducing cattle prices through a shift in farm demand. One can speculate as to why this may be occurring. On the retail side, it may be due to our definition of retail beef prices, which is technically only a subset of retail prices being that ground beef does not encompass all cuts. On the farm side, it may be due to price rigidities arising from hedging efforts such as the use of futures contracts. Alternatively, it could be a case of competition: retailers and cattle farmers may fear increasing their prices or may be unable to due to the large amount of competition in their sectors. Wholesalers, being mostly dominated by four firms, and having prices which are determined by continuous contract-bargaining, do not share these same concerns, and have more autonomy to raise prices.

The results of this paper provide even more talking points for those concerned with the competitiveness, or lack thereof, of the beef supply chain. Namely, looking at the elasticities of price transmission, one can see that a one percent increase in wholesale prices is associated with a 0.13% increase in retail prices. On the farm side, a one percent increase in wholesale prices is associated with a 0.21% increase in farm prices, all else equal. Both price changes are relatively low. However, looking at the results from the wholesale sector, a one percent increase in retail prices increases wholesale prices by 1.48%, and a one percent increase in farm prices increase wholesale prices by 1.34%, all else equal. These price changes are far greater than in the former cases. There are a variety of potential implications that arise from the results. One implication is that these results are consistent with the idea that competitive markets face more elastic market demands due to a lack of pricing power. Therefore, when exposed with greater input costs (through higher wholesale prices), retailers are unable to increase prices as much as they might like. On the other hand, when farm demand increases due to demand changes in the wholesale sector, cattle farmers are unable to increase prices due to intense competition in the cattle industry. This is in stark contrast to the wholesale sector, which, when faced with higher input costs (higher cattle prices) or greater demand to retail demand changes, can increase prices by a relatively large percentage due to their market and pricing power. By no means do these results provide a definitive answer as to the extent of competition or anti-competition in the beef supply-chain. For instance, the lack of price flexibility in the farm and retail markets could be a case of regular price rigidities in those sectors. Therefore, the results merely add to related discussion in the context of COVID-19 discourse.

CONCLUSION

This paper proposed a theoretical model of the beef supply-chain and estimated the model with data over a 30-week period in 2020. The econometric estimation provides strong support for the model's explanatory power in the wholesale and retail sectors and moderate support for the model's explanatory power in the farm sector. A number of variables, as defined by this analysis, are found to be statistically irrelevant in determining prices in the beef supply-chain. However, the findings indeed show that COVID-19 local and total spread has significant influence on wholesale beef prices. Notably, it is estimated that for each 0.01 percentage point increase in the weekly local rate of COVID-19 contraction, there is a 103% increase in the price of wholesale beef per hundred pounds. At the end of April, when local spread was at its peak, a 0.002 percentage point increase in the local rate of contraction was recorded. According to the model, this increase would have the impact of increasing wholesale beef prices by about 21%. Because the USDA data indicates that 18.84 million pounds of wholesale beef were purchased that week, and the wholesale price of beef was $272.33 in the week prior, it can be estimated that the total additional costs to retailers, driven only by increased input prices in that week, was approximately $10.77 million.

There is much more research to be done on the effects of COVID-19, especially as it relates to food and livestock markets. And, as data becomes more readily available, more and more interesting questions will arise which are to be examined by future research, potentially building on the shortfalls of this analysis. One clear limitation of this study is the aggregation of measurement to the entire United States. Panic, stay-at-home procedures, and expectations affect different regions differently. This is likely a contributing factor as to why the coefficients were found to be insignificant in this analysis. Future research should take these into regional differences into account to develop a more complete model that can recognize geography. Another shortfall is the apparent lack of linearity in the relationships amongst the model's variables, especially in the wholesale sector. Expanding the statistical toolkit in future analyses could improve the model fit. Finally, there is a limitation in that ground beef prices are used to represent the entirety of retail beef prices. As data becomes more available (perhaps monthly BLS prices) on retail prices, these can be used to improve the econometric analysis to broaden the implications.

Moving forward, it will be interesting to see if there are any structural transformations in the beef supply-chain. Arguably, the industry's extreme consolidation is what rendered it so vulnerable to a pandemic in the first place. Having so many workers in such tightly packed spaces was simply incompatible with social-distancing protocols and anti-spread measures. Although it could be efficient, both economically and politically, to consolidate beef production as much as possible, it could also be the case that Americans see a shift towards locally sourced beef products, which may be packed in smaller, less concentrated plants. Already, Americans are beginning to voice their concerns about the lack of transparency in the food system and are demanding a greater number of locally-grown food items as a result. After all, such a shift away from consolidation may be the best way to strengthen the resiliency of the food system. More likely, though, because of intense lobbying efforts, high fixed costs, strict federal regulations, and American's love for cheap food, consolidation may remain the status quo.

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APPENDIX

Table A: Additional regression output

Dependent Variable	$1/P^w$	$1/P^f$
Intercept	-0.006***	0.0075***
$\ln(P^r)$	2.10***	
$\ln(P^w)$		0.62***
$\ln(P^f)$	0.52***	
X	0.52**	
Y	-0.35***	0.252
Z		-0.0000079
R-squared	0.86	0.44
R-squared adjusted	0.84	0.37
F	57.76***	2.98**

***—significant at 1%, **—significant at 5%, *—significant at 10%