Demand Shocks and Supply Chain Flexibility*

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Abstract

This paper analyzes supply chain flexibility with uncertainty in consumer demand. As the circumstances regarding COVID-19 showed, large shocks to food demand can create problems exacerbated by the inflexibility of the food supply chain. This model gives a framework for food waste caused by large shocks to food demand. While flexibility in the supply chain may help stabilize the food supply, the effects on firm profits is ambiguous. Policies that consider increasing the flexibility of the supply chain and/or mitigating the impacts of changes in food demand are considered.

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1 Introduction

The COVID-19 pandemic caused a shock to consumer demand for food, which then caused demand shocks throughout the food supply chain. The pandemic and the need for "social distancing" caused a sharp decrease in eating in restaurants, hotels and schools. As consumers quickly switched from dining out to eating at home, surpluses and shortages arose. One important issue that evolved was that the supply chain was not flexible enough to fully accommodate consumers. Many food inputs were wasted because it was already in the supply chain and was slotted for production in segments that had a sharp decline in consumer demand. This paper models the effects of large consumer demand shocks on prices, profitability, and food waste, and we also discuss possible solutions.

Figure 1 shows the rapid and massive shift away from eating in restaurants in 2020 in the United States. Reservations in restaurants vanished in March and still did not fully recover one year later. Conversely, Figure 2 shows the large spike in grocery sales in the United States. There was a very large shock in March of 2020 and sales have continued to be higher than pre-COVID-19 levels. While there was a large shift from eating at restaurants to eating a home, the decline in restaurant sales and the increase in eating at home did not create a uniform change across all types of foods sold at restaurants or grocery stores. For example, many restaurants were still able to continue to serve consumers via a drive in or delivery service, but this still represented a shift in the types of food consumers ate from restaurants. Consumers that ate at home flocked towards "comfort foods" such as frozen pizza, macaroni and cheese, and liquor (Chaudhuri 2020). This dramatic shift in food demand caused volatility for food prices and large amounts of food to be wasted including the destruction of milk, eggs, onion, cabbage, beans, potatoes, cucumbers, squash, and other food inputs (Yaffe-Bellany and Corkery 2020; Ebrahimji 2020; Jeffery and Newburger 2020). This food waste led to uncertainty in the food supply chain and concerns over increasing global food insecurity (Yeung 2020).

Given the relatively constant aggregate food consumption, demand for many types of food sharply increased. Even in dairy, after much of the milk was initially wasted, prices sharply increased once demand started to rebound (Ellis 2020). Other commodities such as wheat and liquor have seen higher than usual demand. Some of the shifts in prices from COVID-19 were even more specific than a particular commodity. In many instances, the change in the demand for inputs depended upon the viability of certain types of production. For example, restaurants sometimes buy eggs in liquid form, but these eggs are then difficult to get into the grocery store supply chain, which then caused a drop in liquid egg prices and an increase in egg prices at grocery stores (Linnekin 2020). Similarly, since chicken wings are generally consumed in restaurants, demand for wings decreased while demand for other parts of the chicken increased (Repko and Lucas 2020). These examples present efficiency problems when the food supply chain is disrupted.

However, there is also a clear cost in creating flexibility in the food supply chain. In the absence of large demand shocks, segmented supply chains allow for product differentiation more choice for consumers. For example, if food is differentiated by not only restaurant/grocery sales, but also GMO/nonGMO or local/non-local, often times separate supply chains are beneficial. There also may be a cost to creating inputs that can be used in multiple supply chains.

The existing literature has been extensively looking at the economics of supply chain design and supply chain management, yet conceptual modeling and analysis of supply chain flexibility and how various players along a supply chain respond to demand shocks is lacking. This research models a shock to consumer demand and analyzes the conditions under which changes should be made in the supply chain. We also discuss solutions that could focus on mitigating shocks and bring consistency to food demand. A distinctive feature of this conceptual framework is that we explicitly model the benefits and costs of introducing a versatile good to the supply chain system, which can be viewed as an insurance vehicle and risk management tool for supply chains.

Broadly speaking, this paper relates to four strands of literature. The first strand of literature is consumer behavior with regards to food. Prior to COVID-19, there have been many instances over the last few decades of both gradual and abrupt shifts in consumer demand for food. Consumer preferences have changed gradually for a myriad of factors including organic, GMOs, local, and many other factors. There have also been rapid changes in demand as well including the Alar scare, e coli outbreaks, and other food safety concerns. However, the COVID-19 pandemic created a very broad, large and quick shift in eating habits and therefore had a dramatic impact on the food supply. Hobbs (2020) discusses consumer behavior during COVID-19 and argues that it may have a long-term impact on food supply chains. For example, these disruptions may create concerns about traditional food supply chains and gravitate towards local food supply chains. While externalities around non-local food supply chains typically centered on environmental or transportation costs (Winfree and Watson 2017), it could also be the case that supply disruptions are also an externality. Disruptions in traditional supply chains could also hasten the use of online food sales (Chang and Meyerhoefer 2020). There may be a long-term shift in consumer preferences that influence the food supply chain.

Understanding consumer behavior alone may not capture the full picture as some of the food supply distortions were not consumer demand driven. For example, meat shortages during early months of COVID-19 were largely caused by virus concerns in meatpacking plants (Repko and Lucas 2020). However, this exacerbated supply chain problems caused by changes in consumer demand. This created a clear benefit for the supply chain to increase its flexibility. For example, for some processing plants, it was simply too costly to produce goods for grocery stores instead of restaurants (Yaffe-Bellany and Corkery 2020). Also, the disruptions eliminated many vertical relationships, making it too difficult for some upstream producers to find downstream buyers. For example, many local food systems and "farm to table" supply chains were devastated (Severson 2020).

The second strand of literature focuses on understanding the economics of supply chain design under uncertainty. For example, Du et al. (2016) examine how the efficiency of a supply chain might be impacted by quantity decisions as well as contracting/integration decisions. This research shows the optimal decisions often depend on the level of uncertainty. Zilberman et al. (2019) show that the design of the supply chain can also factor into the innovation or efficiency of the food supply. Also, Fang and Shou (2015) examine the relationship between supply chain uncertainty under various degrees of market competition. We add to this literature by showing that the profitability of using versatile inputs depends on many factors such as the potential size of shocks and costs of inputs.

Yet, this line of research does not focus on the modeling of optimal decision on the flexibility in the food supply chain, which has been increasingly rigid in recent years, in part, because of the specificity of inputs. With the increases in varieties of various commodities, various inputs have become more unique, which in turn may increase the benefit of contracting and vertical relationships. The increasing heterogeneity in consumer preferences, as well as market power effects, has created many incentives for producers to engage in supply chains that resemble silos instead of markets with many buyers and sellers. For example, the rise in the "buy local" movement in recent years has increased the segmentation of supply chains.

The third strand of literature focuses on understanding the economic impact of COVID-19 and rapidly emerging mitigation strategies. Lusk et al. (2020) provides a comprehensive overview of the economic impact of COVID-19 through 16 topics such as the impact of COVID-19 on US food supply chain, international trade, retail, rural health care etc. Reardon et al. (2020a) analyze the impact of COVID-19 on food supply chains in developing countries. They find that COVID-19 may have large impacts, in terms of higher prices and shortages, for small and medium sized businesses in urban markets in these developing countries.

The COVID-19 pandemic has shown the consequences of having an inflexible supply chain. Contracts and growing commodities for very specific types of consumption creates a supply chain that may not be able to move as swiftly as necessary. However, there are ways to increase supply chain flexibility. In some instances, certain varieties of inputs are more flexible. Also, some types of food packaging could be changed so that it could be more versatile with either restaurants or grocery stores. There may also be solutions to entail either mitigating changes in consumer demand or making the final products more versatile (e.g. restaurant delivery). Gray (2020) looks at logistical issues created by COVID-19 to the food supply. Other studies have concentrated on specific industries, from more fragmented sectors such as fruits and vegetables (Richards and Rickard 2020), to relatively more concentrated meat sector (McEwan et al. 2020), from early struggles of hog farms in China (Zhang et al. 2020) to the recent innovations in e-commerce and other resilience innovations (Reardon et al. 2020b). Our conceptual framework allows for a hedonic demand analysis on the potential market for such innovations.

Finally, our model also relates to the literature on food waste. For example, Bellemare et al. (2017) show that many estimates of food waste are difficult and inconsistent with each other. Part of the problem is that there can be many stages of food production and so there are many sources of food waste. Hamilton and Richards (2019) focus more on household waste and how that can be reduced. Our model is in contrast to this where we focus on food waste early in the production cycle between upstream and downstream firms.

This paper makes two contributions to the literature. First, our model helps explain why food waste and shortages may occur with dramatic shifts in consumer demand and what may be done to solve this issue. In particular, Supply chains may be able to become more versatile to handle such shifts in demand. Second, this paper provides a new angle on evaluating the various mitigation strategies and policy responses to COVID-19.

2 Model

This section models the effects of supply chain versatility on prices, profits, and food waste. More specifically, we model two types of consumer goods and inputs are considered versatile if they can be used by downstream firms to produce either type of good.

While producing versatile inputs comes at a higher cost, it also has an option value that depends upon consumer demand shocks and the associated prices. Our model has three stages. First, upstream producers choose the type of input to produce based on expected consumer demand. Second, a demand shock is realized and downstream firms process the goods based upon the updated consumer demand. Third, consumers purchase goods from downstream firms.

Upstream producers produce a fixed quantity (set equal to one) of inputs and the inputs can be of three types: input 1, input 2, or a versatile input, denoted by x_1, x_2 and x_v. We denote the aggregate inputs produced in the market by X_1, X_2 and X_v. While input 1 must be used for good one and input 2 must be used for good 2, a versatile input can be processed as either type of good.[1] The cost of each type of upstream input is c^{u1}, c^{u2}, and c^{uv} where $c^{uv} > c^{u1} = c^{u2}$. The inputs are then used downstream to be processed at a cost of either c^{d1} or c^{d2} where $c^{d1} = c^{d2}$. The goods are then consumed by consumers. This structure for the supply chain is shown in Figure 3.

Firms make their input choices based on expected prices and consumer demand for goods are given by,

$$p_g^d = a + \epsilon_g - BQ_g - bQ_{-g} \tag{1}$$

where p_g^d is the price between the downstream firm and the consumer for good $g = \{1, 2\}$. a, B and b are parameters that represent consumer preferences and substitution between the two goods. These parameters are symmetrical between the two goods and $B \geq b$. Note that the two goods are not vertically differentiated, but they are horizontally differentiated as long as $B > b$. ϵ is a random variable that represents a demand shock and is distributed at $\epsilon \sim U(-\bar{\epsilon}, \bar{\epsilon})$. Q_g represents the aggregate quantity consumed of good g, which is also equal to the total amount of inputs used by downstream firms to

[1] Examples of this might be to produce different varieties, of which some are more flexible or versatile. For example, potatoes, wheat and apples have different varieties with varying flexibilities. Also, some inputs in the food supply chain can be produced or packaged so that they can go through either wholesale or retail supply chains.

produce that good.

We would note that while sales dramatically decreased for restaurants and increased for grocery stores, this does not necessarily imply that grocery stores had a positive shock to demand via ϵ. Rather, COVID-19 caused a decrease in demand for restaurants due to health concerns, therefore demand for grocery stores increased because of the drop in substitutes. In other words, demand for grocery stores increased via bQ_{-g}. In fact, it may be the case that grocery stores also had a negative impact due to health concerns, but this effect was swamped by the even larger health concern for eating at restaurants.

We assume that downstream firms compete on prices with Bertrand competition. Therefore, demand stemming from downstream firms for upstream inputs is equal to consumer demand minus processing costs. Therefore, the demand for inputs is given by,

$$p_g^u = a + \epsilon_g - BQ_g - bQ_{-g} - c^d \tag{2}$$

where c^d is the processing costs and is equal for both types of good and independent of the type of input (versatile vs. non-versatile). Depending upon the demand shocks, there are three possibilities for prices once the demand shocks are known. First, prices may equalize if enough versatile inputs are produced. If the shocks are relatively similar, then prices will be the same since upstream producers can choose which goods to process. There is no option value to producing a versatile input in this case since prices are the same. Second, one input price may be higher than the other, but both are positive. If the shocks are different enough, but neither is drastically negative, then prices will diverge. In this case, producers that produced the versatile input will receive a higher price than one of the inputs. Third, it may be the case that at least one of the input prices is zero. If a demand shock is large and negative, there may wasted inputs because of a lack of demand. This does not imply that there is no production in that market, but rather there is such an excess of production that the price goes to zero and a portion is wasted.[2]

[2]Mathematically, the third case could be further broken down into two cases. In one case, prices are zero, but some inputs are being used in the market while some inputs are wasted. In the other case, the negative shock to demand is so large that there is no market and all inputs are wasted. We assume that

Exercising an option value on a versatile input only occurs when all of the versatile inputs are used for one good. In other words, if versatile inputs are used in the processing of both goods, this implies the prices are equal because of competition between processors. Therefore, there is a threshold where all the versatile production goes to one good and prices start to diverge. This threshold occurs when the differences in the shocks are large relative to the amount of versatile inputs produced. Suppose that $\epsilon_1 > \epsilon_2$, since $X_1 = X_2$ due to symmetry, the threshold for this is $\epsilon_1 - \epsilon_2 = [B - b]X_v$. This implies that if $\epsilon_g - \epsilon_{-g} > [B - b]X_v$ and both prices are still positive, then the difference in prices is given by,

$$|p^u_g - p^u_{-g}| = |\epsilon_g - \epsilon_{-g}| - [B - b]X_v \tag{3}$$

However, this assumes that both prices are still positive. There is also another threshold when p^u_1 or p^u_2 goes to zero. Again, assume that $\epsilon_1 > \epsilon_2$. In this case, $p^u_2 = 0$ if $a + \epsilon_2 - BX_2 - b(X_1 + X_V) - c^{d2} \leq 0$. In this circumstance, all of the versatile inputs have gone to good 1, but there is not enough demand for good 2 for a positive price. This is not to say that all of the inputs are wasted, but if demand is small enough that some of the inputs are wasted, then the price will go to zero. Therefore, if this threshold is met and $-\epsilon_{-g} > a - BX_{-g} - b(X_g + X_V) - c^{d-g}$ then using $c^{d1} = c^{d2}$ the difference in prices is given by,

$$p^u_g - p^u_{-g} = p^u_g = \frac{(a - c^d)(B - b) - [B^2 - b^2](X_g + X_v) + B\epsilon_g - b\epsilon_{-g}}{B} \tag{4}$$

since, in this case, the actual amount of goods used, Q_{-g} is not the same as the actual amount of inputs produced specifically for that good, X_{-g}. These two thresholds then create 3 zones: a zone with equal prices and no option value for versatile inputs, a zone with unequal but positive prices with a positive option value, and a zone with only one

$\bar{\epsilon}$ is sufficiently small that it does not collapse the entire market.

positive price and an option value.

Equations (3) and (4) then allow us to calculate the option value of producing versatile inputs over nonversatile inputs. Using the two aforementioned thresholds, we calculate four values on Figure 4, so that if $\epsilon_1 > \epsilon_2$ we calculate the option value of versatile inputs over inputs for good 2, then the values on Figure 4 are given by, $\epsilon_1^* = \frac{1}{B}\left[b\underline{\epsilon} - (b-b)(a-c^d) + (B^2-b^2)(X_1+X_v)\right]$, $\epsilon_1^{**} = c^d - a + B(X_1+X_v) + b(X_1)$, $\epsilon_2^* = c^d - a + BX_1 + b(X_1+X_v)$ and $\epsilon_2^{**} = \overline{\epsilon} - (B-b)X_v$.

An option value can be represented by

$$OV = \frac{E[|p^{u1} - p^{u2}|]}{2} = E[\max(p^{u1}, p^{u2})] - E[p^{u2}] \tag{5}$$

Again using Figure 4, this can be calculated by finding the probabilities and expected values for the various zones when the price for good 1 is greater than good 2. Mathematically,

$$OV = \sum \frac{Pr}{A} \int\int Max[p_1 - p_2, 0] d\epsilon_2 d\epsilon_1 \tag{6}$$

where the various zones are summed, Pr is the probability the demand shocks will be in that area, and A is the size of the area. The option value can then further be represented by,

$$OV = \frac{1}{\overline{\epsilon}^2}\left[\int_{\epsilon_1^{**}}^{\overline{\epsilon}}\int_{\epsilon_2^*}^{\epsilon_1-\phi} \epsilon_1 - \epsilon_2 - \phi d\epsilon_2 d\epsilon_1 + \int_{\epsilon_1^{**}}^{\epsilon_1^*}\int_{\underline{\epsilon}}^{\underline{\epsilon}+\frac{b}{B}\epsilon_1^* - \frac{b}{B}\epsilon_1} p_1 d\epsilon_2 d\epsilon_1 + \int_{\epsilon_1^{**}}^{\overline{\epsilon}}\int_{\underline{\epsilon}}^{\epsilon_2^*} p_1 d\epsilon_2 d\epsilon_1\right] \tag{7}$$

where $\phi = (B-b)X_v$. If we let $d_1 = \epsilon_1^{**} - \epsilon_1^*$, $d_2 = \overline{\epsilon} - \epsilon_2^{**}$ and $d_3 = \epsilon_2^{**} - \epsilon_2^*$ then the option value is calculated as,

$$OV = \frac{1}{\overline{\epsilon}^2}\left[\frac{d_3^3}{6} + \frac{bd_1^3}{3B}\left(1 - \frac{b^2}{2B^2}\right) + \frac{d_2 d_3}{2}\left(d_3 + \frac{b}{B}d_2\right)\right] \tag{8}$$

This represents the option value of producing versatile inputs instead of inputs of good 2. Given the symmetry of costs and expected values, the option value would be the same for versatile inputs compared with inputs for good 1. Further, this option value is the aggregate option value for all producers. The option value can be decomposed into $\frac{1}{\epsilon^2}\frac{d_3^3}{6}$ when prices are positive and unequal, and $\frac{1}{\epsilon^2}\left[\frac{bd_1^3}{3B}\left(1-\frac{b^2}{2B^2}\right)+\frac{d_2 d_3}{2}\left(d_3+\frac{b}{B}d_2\right)\right]$ where one price is equal to zero.

Upstream firms are then based with a decision: they can either produce nonversatile or versatile inputs. Upstream firms make this decision based upon the option value of the versatile input versus the extra cost of the versatile input. Upstream producers will produce versatile inputs until the following condition is met,

$$OV = c^{uv} - c^{ug} \tag{9}$$

This is because the benefit of producing versatile inputs is equal to the option value and the cost is simply the differences in cost between versatile and nonversatile inputs. Thus, there is an equilibrium amount of versatile inputs that is perhaps best described intuitively. If there are no versatile inputs, then the probability of equal prices is zero and the option value is maximized. If there are many versatile inputs in the supply chain, there is a greater likelihood of equal prices and the option value is lowered.

The model illustrates various price outcomes in the supply chain. If demand shocks are relatively equal, prices equilibriate and there is no advantage to producing versatile goods. On the other hand, prices can vary widely depending upon the shock to demand. In general, there was an increase in prices at grocery stores for many goods while prices at restaurants dropped in the Spring of 2020. For example, while the price for fresh eggs rose dramatically in the Spring of 2020, many egg producers went bankrupt since they sold liquid eggs. Food waste, such as destroying potatoes or dumping milk is illustrated by the upper left and lower right areas of Figure 4. Producers dumping milk came at the same time that ice cream sales increased, illustrating the various supply chains.

While versatility in the supply chain helps stabilize the food supply and creates less food waste, its effects on profits are ambiguous, and therefore may not be desirable for the firms. First, the change in cost due to versatility is clear. Since $c^{uv} > c^{u1} = c^{u2}$, versatility will increase costs. On the revenue side, since total revenues for all firms is given by aggregate quantities multiplied by prices, the effect of versatile inputs on total revenues is given by,

$$\frac{dTR}{dX_v} = \sum_g \left[\frac{dp_g}{dX_v} q_g + \frac{dq_g}{dX_v} p_g \right] \tag{10}$$

The sign of this is ambiguous. Versatility depresses the price of the good with the higher demand/quantity and buoys the price at the same rate of the good with lower quantity, therefore $\sum_g \frac{dp_g}{dX_v} q_g \leq 0$. Simultaneously, quantities are being shifted to the good with the higher prices, so $\sum_g \frac{dq_g}{dX_v} p_g \geq 0$. Thus, the impact on total demand depends upon the magnitudes of the prices and quantities. If the disparity between the quantities is large relative to the difference in prices, supply chain versatility will decrease aggregate revenues.

However, more versatile inputs will also reduce risk. Since the versatile inputs help stabilize prices, the variability of revenues decreases. Therefore, risk averse firms may prefer more versatility.

3 Mitigation Strategies and Policy Implications

3.1 Increasing Input Versatility

Mathematically, the effect of increasing versatile inputs on input waste is given by

$$\frac{d\Xi}{dX_v} = \frac{1}{2} \left[\frac{d_2}{2} \left((B - b) - (B^2 - b^2) \right) - (d_1 + d_3)(B - b) \right] < 0 \tag{11}$$

where Ξ represents food waste. While versatility may be the goal of a policymaker, it is not obvious how to increase the versatility of these inputs. Although it may be difficult to overhaul upstream inputs, some versatility strategies were implemented in markets. For example, some food service distributors started supplying grocery stores.[3] Similarly, ghost kitchens picked up some of the slack caused by supply chain disruptions. Also, online food sales and food banks helped maintain some of the food supply. If these avenues are flexible, there may be an incentive to increase the size of these types of food sales. However, recent disruptions may also warrant changes further up the supply chain by implementing such policies as more uniform packaging.

It is important to note, more flexible markets may also reduce market power. The trend in food is to have differentiated food (organic, GMO, local, etc.), so while a more uniform food supply may reduce food waste if there are large shocks to consumer demand, it may also decrease profits. Nonetheless, it may be beneficial for policymakers to give incentives for a more versatile food supply chain.

3.2 Reducing Demand Shocks

Aside from creating versatility in the supply chain, there are strategies to reduce shocks in demand. The most straightforward strategies might be to limit changes in regulations and restrictions. During the COVID-19 "lockdowns", there were clear reasons to reduce restaurant services. However, virus considerations may need to be balanced with food shortage considerations if the shocks are severe.

It is intuitively clear, and clear from the model that $\frac{d\Xi}{d\bar{\epsilon}} < 0$, meaning that shock mitigation would lead to less food waste. Examples may entail limiting capacity instead of eliminating all services, making restrictions more geographically specific, or encouraging alternatives such as drive-throughs. Also, a lack of grocery licenses prevented some restaurants from selling directly to consumers, which would have helped mitigate shifts in consumer demand (Linnekin 2020). Of course, these policies, especially when initiated very quickly, can be difficult to weigh both the costs and benefits. However, to the extent

[3] https://www.cnbc.com/2020/03/27/restaurant-suppliers-pivot-to-grocery-direct-sales-during-coronavirus-pandemic.html

that food shortages may be a concern, an alternative to creating input versatility would be to reduce demand variability. This would be especially true if decisions are made in the short run and input versatility cannot be changed.

Similarly to increasing supply chain versatility, reducing demand shocks may decrease profitability for firms. Since prices are bounded at zero, losses are also bounded and therefore the effects of larger shocks are asymmetrical. However, this might change if different distributional assumptions are made about the shocks. Nonetheless, firms may want siloed supply chains with large demand shocks.

4 Discussion

This model is meant to illustrate the effects of large shocks to consumer demand that influence the food supply chain. This model illustrates a scenario where shocks can create food waste due to separated supply chains, but at the same time, profits can go up. This seems to be consistent with the empirical findings of 2020. In the state of Idaho, many potato and dairy inputs were wasted, but overall farm receipts increased Carlson (2021).

Qualitatively, this shows us the possible incentives for policymakers. Under reasonable assumptions, siloed supply chains may increase expected profits. However, it will also increase the risk of producers since it increases the variability in prices and increases the probability of wasted inputs. Siloed supply chains might also be beneficial for some consumers if it is associated with product differentiation and more consumer choice. However, if food waste has associated externalities, then there may be an incentive to create more versatility in the food supply chain or reduce the size of demand shocks.

There are a few ways policymakers might be able to mitigate the effects of large demand shocks. Most obviously, policy restrictions on eating habits should take into account the strain on the supply chain. More long term solutions may be standardized packaging or alleviating restrictions on food sales. Policymakers should consider the empirical estimates of these various costs and benefits. In some situations, there may be a need for intervention.

5 Conclusion

This paper provides a framework to illustrate how input versatility may impact the food supply chain, prices and food waste/shortages. Producing inputs that have versatility in the supply chain can stabilize prices and reduce food waste. However, it is not clear that producers would prefer siloed supply chains depending upon the differences between prices, quantities and costs. The recent COVID-19 pandemic has illustrated the possibility of quick, large shocks to consumer demand for virtually all types of food.

While food differentiation may alleviate some types of risk in the food supply, it can also increase risks if consumers start to rely on certain types of food. The current food supply chain seems to become more and more fractured with various food types such as organic food, GMOs, local supply chains and various other attributes. This is in addition to the critical distinction of wholesale versus retail food. Given the obvious necessity of eating and therefore the somewhat stable aggregated demand for all types of food, a sudden shock to a segment of the food supply can cause an enormous strain on other segments of the food supply. Therefore, this model could potentially be used for various distinctions throughout the supply chain.

There are various mechanisms that can be used to try to remedy a lack of versatility. Subsidization of versatility may alleviate food waste. Also, technology may be able to more quickly adapt inputs into various outputs. Alternatively, creating more consistency in food demand and mitigating demand shocks may also be helpful. While the food supply may be very resilient in adjusting to long-term changes in demand Baldos and Hertel (2016), it seems less clear in the short-run. Decisions about the food supply chain should take into account these various costs and benefits.

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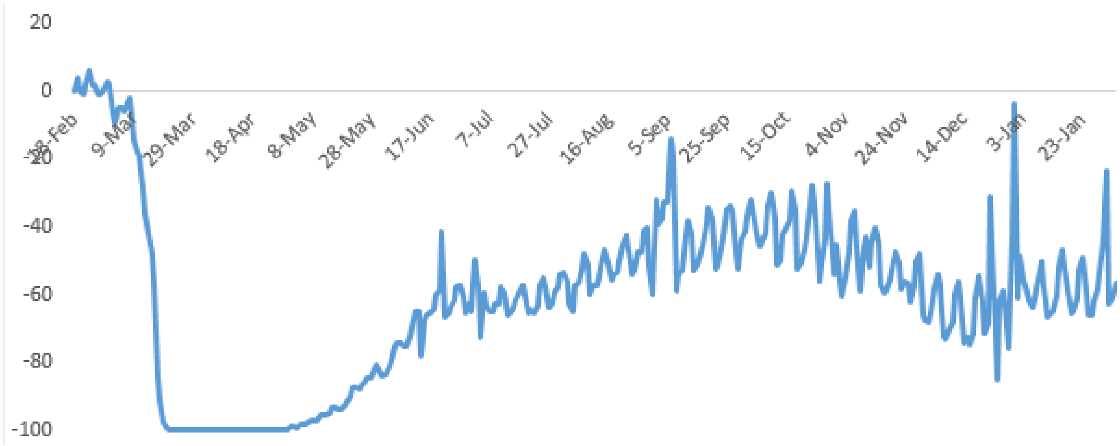
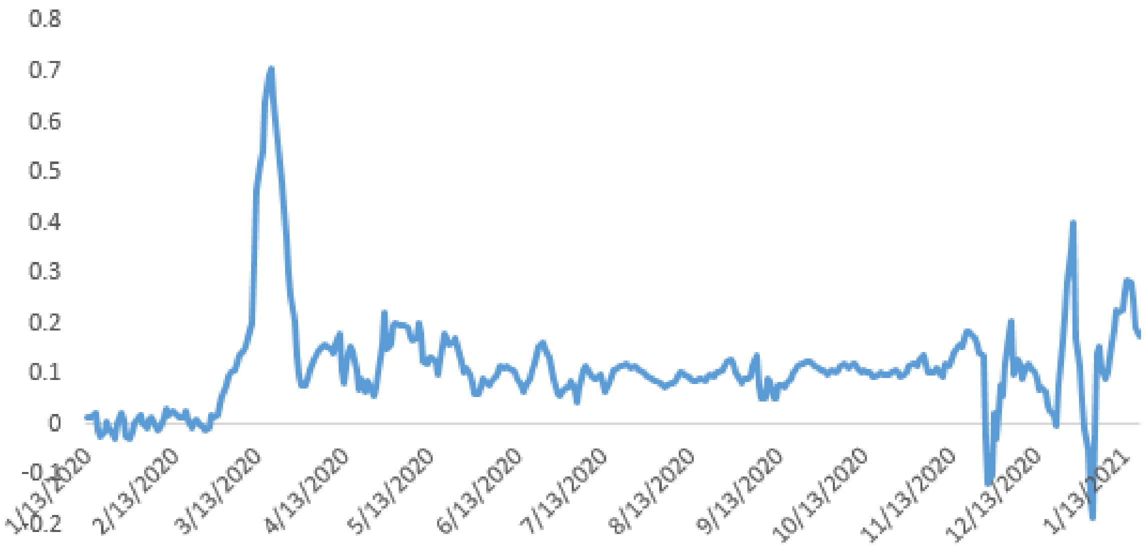
Figure 1: Change in seated diners from online, phone, and walk-in reservations in the United States from 2019 to 2020[4]



[4] Data are from https://www.opentable.com/state-of-industry. Only states or metropolitan areas with at least 50 restaurants in the OpenTable network were included.

Figure 2: Change in grocery sales in the United States from 2019 to 2020[5]



[5]Data are from Affinity Solutions and represent "Seasonally adjusted credit/debit card spending relative to January 4-31 2020 in grocery and food store (GRF) MCCs, 7 day moving average."

Figure 3: Supply Chain Illustration

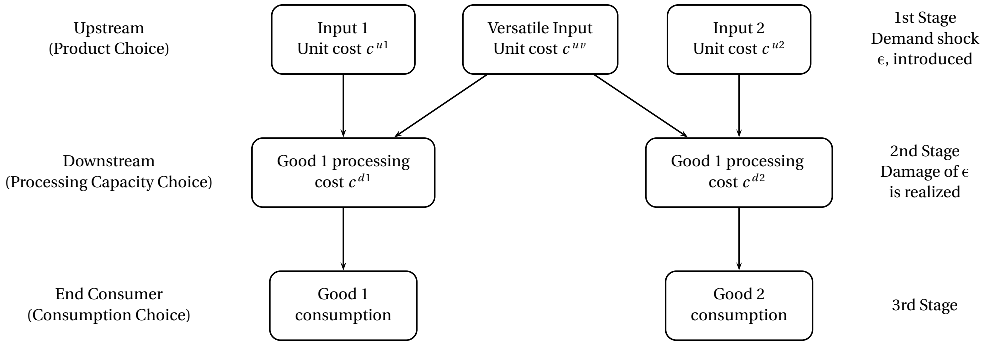


Figure 4: Demand Shocks and Price Differences