# Supply and Demand Indicies and Their Welfare Implications

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**Abstract**
This paper provides a structural interpretation of commonly used commodity demand indicies that, when coupled with a newly introduced supply index, can be used to calculate welfare changes over time. The new supply index measures changes in marginal cost or, inversely, the change in the quantity producers are willing to supply at a given price. The supply index is an easy to calculate commodity- and geographic-specific alternative to commonly used aggregate total factor productivity measures. These demand, supply, and welfare indicies can provide timely information about the economic fundamentals in a market that can be coupled with other data to analyze structural adjustment patterns. Empirical applications are presented for the U.S. cattle, hog, and chicken sectors and for county-level corn supply. Beef cattle supply and demand grew rapidly from the 1950s to the 1980s, after which cattle demand fell before recovering in the mid-2000s. Supply and demand improvements have led to significant gains in producer and consumer welfare over time. Cattle supply indicies have been stagnant for the past couple decades while hog, and especially chicken, supply indicies have increased. The supply and demand indicies correlate in intuitive ways with factors such as corn prices, drought, aggregate agricultural total factor productivity, gross national product, and exchange rates. Trends in disaggregate corn supply indicies reveal marked heterogeneity across U.S. counties with the largest gains since 1980 being observed in the Dakotas, Kansas, Missouri, and the Mississippi Delta. Many areas of Ohio and Indiana have experienced negative corn supply shocks in 2018-2016 relative to 2000.

**Keywords**: beef, chicken, demand index, equilibrium displacement model, pork, productivity, supply index, welfare

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In 2015, per-capita beef consumption in the U.S. reached a record low of 54 lbs/person, falling almost 20% over the prior decade from 2005 to 2015 alone (USDA, Economic Research Service, 2020). Why? Some environmental, public health, and animal advocacy organizations heralded the decline as an indicator of their efforts to convince consumers to reduce their demand for beef; others argued, instead, the change was a result of supply-side factors such as drought and higher feed prices (e.g., Strom, 2017). Per-capita beef consumption subsequently rebounded, and in 2018 was almost 6% higher than in 2015. Dramatic fluctuations in corn, soybean, and wheat prices in the late 2000s through the mid-2010s led to similar heated debates about whether and to what extent price rises were due to demand (e.g., biofuel policy and rising incomes in China) or supply (e.g., drought in various regions of the world) factors (e.g., Abbot, Hurt, Tyner 2019; Carter, Rouser, and Smith, 2016; Hochman, Rajagopal, and Zilberman, 2010; Roberts and Schlenker, 2013). These cases highlight the challenge of interpreting market dynamics and the need for metrics that can decompose price or quantity changes to reveal underlying drivers and consequences.

Because changes in per-capita consumption are often inaccurately conflated with changes in demand among producer and lay audiences, analysts, starting with Purcell (1998), have calculated and disseminated demand indicies that aim to isolate changing consumer preferences. These demand indicies are easy to calculate in a timely fashion and have become key performance indicators for some livestock and poultry commodity organizations, which levy producers to fund demand promotion activities (Bekkerman, Brester, and Tonsor, 2019). Check-off organizations are mandated to evaluate the returns on investments that occur through demand promotion, and researchers continue to investigate the extent to which checkoff and promotion efforts increase demand (Kaiser, 2016). Despite their appeal and simplicity, the demand indicies do not appear to be widely used outside these industries.[1] Wider use of the measures by academics may be limited by the lack of clarity on the relationship between the index and structural supply- and demand-relationships, something this article aims to rectify.

Knowledge of demand indicies are of interest to more than just commodity industry organizations. For example, aforementioned environmental, health, and animal advocacy organizations raise funds to discourage demand, and such demand indicies could serve as performance metrics for such activities, albeit in an inverse direction of that for producer organizations. The potential audience for structural indicies is wider and, consists of parties, including research funders and sustainability advocates, more interested in changes in productivity and supply. As such, this article introduces an analogous supply index, that when coupled with a demand index, can be used to calculate welfare changes over time.

Evidence of the need for supply indicies is suggested by the large literature devoted to measuring changes in agricultural productivity and exploring the relationship between research funding and total factor productivity (TFP) growth (e.g., Alston et al., 2011; Alston, Babcock, and Pardey, 2010; Huffman and Evenson, 2008; Jin and Huffman, 2016). Despite the imminent value of total factor productivity calculations, they are not without drawbacks, including the fact they are often reported with significant lags (e.g., as of this writing the latest benchmark measures of agricultural TFP reported by the USDA Economic Research service are five years old), are typically only available at highly aggregatated levels such as the nation or sometimes the state, and typically only pertain to aggregate output due to the challenge of allocating inputs to multiple outputs. However, there is often interest in more immediate, more geographically

[1] While explicit demand and supply indicies are not, today, widely used among analysts of commodity crops, there are other metrics, such as the stocks-to-use ratio for crops and cold storage volumes for meats, that are closely watched to provide indications of shifting supply and demand patterns, further highlighting the need for timely, easy to calculate metrics on market conditions.

disaggregated information on supply shifts for particular commodities, something a supply index provides.

Calculation of supply and demand indicies and welfare changes only requires four pieces of information for the commodity of interest: prices, quantities, and estimates of the elasticities of supply and demand. As such, supply and demand shifts can be readily quantified as soon as new price/quantity data are made available. It is increasingly being recognized that TFP measures might provide a partial basis of accounting for changes in sustainability (e.g., Gaitán-Cremaschi et al., 2016), and other social challenges including climate change, animal welfare, etc. that involve complex phenomena and easily confounded price and quantity adjustments. In this context, making commodity and location-specific supply indicies available might aid in the attempts to provide more timely metrics of interest to a diverse, and growing audience and enable economists to have an elevated role in discussions of sustainability.

The remainder of the paper proceeds as follows. The next section reviews the calculation of demand indicies that are today used in livestock markets. Then, marginal cost and supply indicies are introduced. The following section shows how supply and demand indicies are related to shocks in equilibrium displacement models, which enables the determination of how the welfare of consumers and producers changes over time. Then, three empirical applications are presented providing a mix of examples demonstrating value and economic insights associated with the indicies. The first application shows trends in supply, demand, and welfare in the beef cattle sector since 1950. The second application contrasts supply and demand indicies in cattle, hog, and chicken, and as a validity check explores how these indicies co-vary with corn prices, aggregate agricultural TFP, drought, gross national product, unemployment, and exchange rates.

The final application explores changes in corn supply indicies across U.S. counties. The last section concludes.

**A Review of Demand Indicies**

The demand index concept originated with Purcell (1998). The basic idea is, after observing a change in quantity and price, to determine the price that would have prevailed at the new quantity level if the demand curve hadn't shifted. Figure 1 illustrates. Consider an initial period where the supply and demand curves are given by $S_0$ and $D_0$. The interaction of these two curves at point A yields an equilibrium price and quantity of $P_0$ and $Q_0$. Now, consider a future period, *t*, when a new lower price and higher quantity are observed, $P_t$ and $Q_t$. The price and quantity changes could have been caused by a change in the position of the supply curve (e.g., from an increase in productivity) or a change in the position of the demand curve (e.g., a reduction in consumer's willingness to pay) or both as shown at the new equilibrium point B.

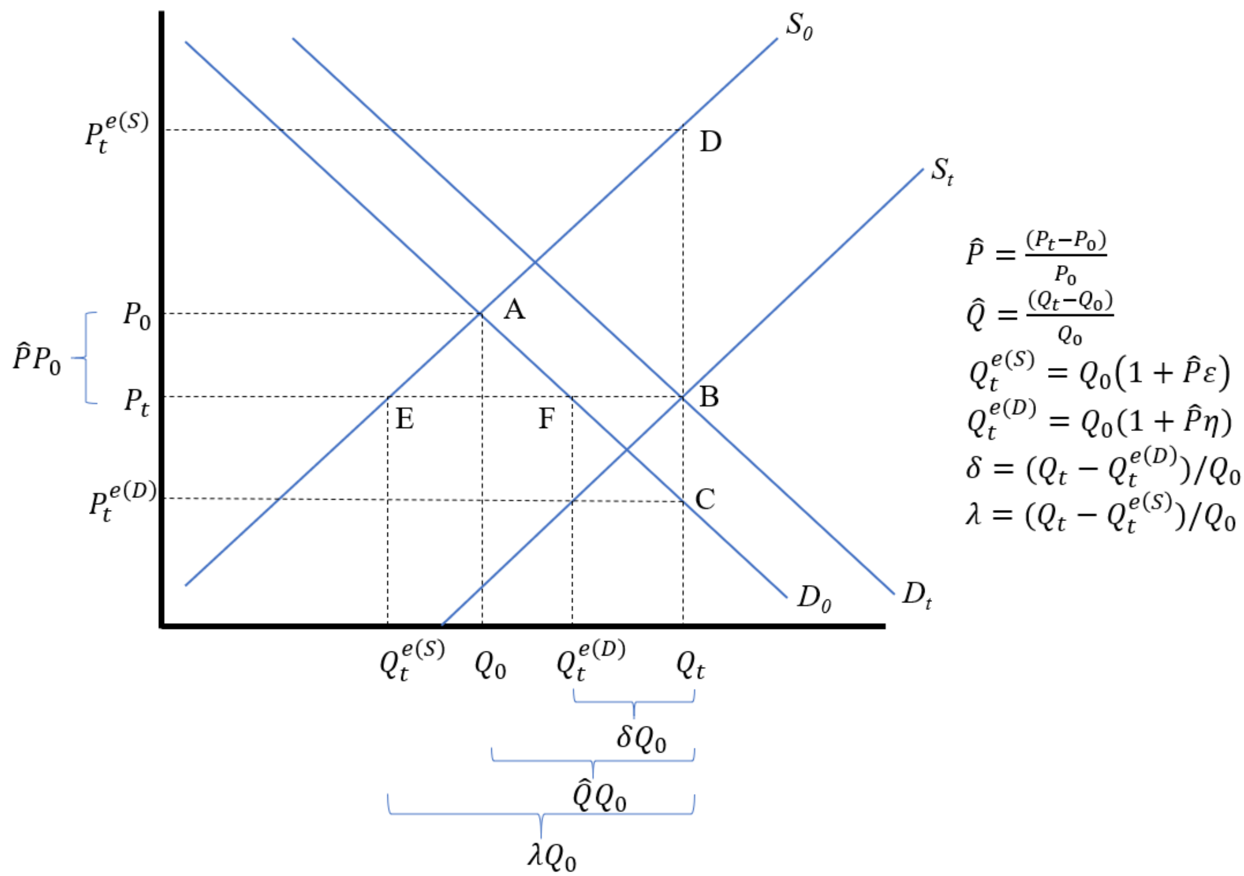


**Figure 1**. Illustration of Demand and Supply Indicies

To determine the extent to which a shift in demand is responsible for the price change from $P_0$ to $P_1$, one can ask the following: If the preferences hadn't changed and the demand curve hadn't shifted (i.e., only movements along the original demand curve $D_0$ occurred), what is the price that would have been required to induce consumers to consume the new quantity, $Q_t$? The answer to this question is found at point C on the original demand curve. This expected price, $P_t^{e(D)}$, is not directly observable but it can be calculated with knowledge of the own-price elasticity of demand, $\eta$.[2] An index is created by comparing the expected price to the observed price. Letting $\hat{Q}$ represent the proportionate change in quantity from time 0 to $t$, $\hat{Q} = \frac{Q_t - Q_0}{Q_0}$, then a demand index is defined as:

(1) $$I^{D,P} = \left(\frac{P_t}{P_t^{e(D)}}\right) 100 = \left(\frac{P_t}{P_0(1+\hat{Q}/\eta)}\right) 100.$$

Bekkerman, Brester, and Tonsor (2019) showed that the index in (1) can be excessively volatile, and they proposed measuring the demand shift horizontally (in the quantity direction) as opposed to vertically (in the price direction). As a result of this distinction, (1) can be referred to as a demand price index or a willingness to pay index. Creating a demand quantity index is analogous to the price counterpart. In particular, we ask, after a change from $P_0$ to $P_t$, what is the quantity consumers would buy if their preferences hadn't changed. In figure 1, this occurs at point F and the expected quantity, $Q_t^{e(D)}$. Letting $\hat{P}$ represent the proportionate change in price from time 0 to $t$, $\hat{P} = \frac{P_t - P_0}{P_0}$, then a demand quantity index is:

(2) $$I^{D,Q} = \left(\frac{Q_t}{Q_t^{e(D)}}\right) 100 = \left(\frac{Q_t}{Q_0(1+\hat{P}\eta)}\right) 100.$$

**Supply Indicies**

This section introduces a new supply index. While the supply index is a straightforward extension of the demand index approach, to our knowledge it has not been previously introduced or used. The motivation is to draw a distinction between the quantity of a good supplied and the position of the supply curve. While the supply curve shows how quantity produced changes with

[2]More accurately, for this initial calculation, a price flexibility is needed; for simplicity and ease of exposition, we assume the flexibility can be approximated by the inverse of the elasticity, $1/\eta$, which is accurate under the assumption of zero cross-price effects (Houck, 1965).

output prices (i.e., movements along the curve), interest also rests with the extent to which the entire curve shifts up or down. Increases in productivity brought about by cost-saving technologies shift the curve downward – producers are willing and able to produce more at a given price. By contrast, adverse weather events or an increase in the cost of an input will shift the curve upward – producers will supply less for a given price.

The question is how to identify the extent to which the supply curve has shifted over time. The following discuses two approaches for measuring supply curve shifts. The first focuses on output price (or marginal cost) changes and the other focuses on quantity changes. Either approach provides a measure of changes in productivity or cost of production as distinct from changes in demand. To measure the extent to which a shift in supply (or productivity) is responsible for the price change, one can ask the following: If the supply curve hadn't shifted (i.e., we could only move along the curve $S_0$), what is the price that would have been expected or required to induce producers to produce $Q_t$? As shown in figure 1, the answer to this question is found at point D on the original supply curve, which is associated with the actual output $Q_t$ and the expected price $P_t^{e(S)}$. This expected price, $P_t^{e(S)}$, is not directly observable but it can be calculated with knowledge of the own-price elasticity of supply, $\varepsilon$.

An index of the change in marginal cost (i.e., a measure of the shift in the supply curve) from period 0 to period *t* can be calculated as the ratio of the observed price $P_t$ to the expected price that would have occurred had the supply curve not shifted, $P_t^{e(S)}$. The marginal cost index is calculated as follows:

(3) $$I^{S,P} = \left(\frac{P_t}{P_t^{e(S)}}\right)100 = \left(\frac{P_t}{P_0(1+\hat{Q}/\varepsilon)}\right)100.$$

A lower number indicates a reduction in marginal cost brought about by factors such as increased productivity, whereas a higher number indicates an increase in marginal cost brought about by factors such as adverse weather, increased costs of inputs, etc.

Given the potential challenges with price-indicies noted by Bekkerman, Brester, and Tonsor's (2019), an alternative supply quantity index is proposed. This approach asks what the quantity is that would have been expected to be supplied at price $P_t$ if the supply curve hadn't shift from period 0 to *t*. This measure is determined at point E in figure 1, and is given by the expected quantity $Q_t^{e(S)}$. By comparing this expected quantity to the actual quantity, a measure of the shift in the supply curve is obtained. As before, the expected quantity, $Q_t^{e(S)}$, is not directly observable but it can be calculated with knowledge of the own-price elasticity of supply as shown in equation (4).

(4) $$I^{D,Q} = \left(\frac{Q_t}{Q_t^{e(S)}}\right)100 = \left(\frac{Q_t}{Q_0(1+\hat{P}\varepsilon)}\right)100.$$

A larger supply index indicates producers in time *t* are willing and able to supply more output at a given price than they were in time 0.

**Structural Interpretations and Welfare**

While the preceding sections lay out the necessary details to calculate supply and demand indicies, it is unclear how they might combine to measure changes in welfare. To draw out these implications, we make use of a simple equilibrium displacement model.

Following Alston (1991) or Wohlgenant (2011), let the demand for a good be expressed in differential form as:

(5) $$\hat{Q}^D = \eta\hat{P} + \delta,$$

where, as previously defined, $\hat{Q}^D$ is the proportionate change in quantity of the good demanded (i.e., $\hat{Q} = \Delta Q/Q \approx \text{dln}Q/Q$), $\hat{P}$ is the proportionate change in price, and $\eta$ is the own-price elasticity of demand. Here, $\delta$ is a demand shock representing the proportional change in consumer's quantity demanded and it is the magnitude of the horizontal shift in the demand curve expressed relative to the initial equilibrium quantity.[3]

The supply of the good, in differential form is:

(6) $\hat{Q}^S = \varepsilon\hat{P} + \lambda,$

where $\varepsilon$ is the own-price elasticity of supply, $\lambda$ is a supply shock representing a horizontal shift in the supply curve expressed as a proportion of the initial equilibrium quantity, $\hat{Q}^S$ is the quantity of the good supplied, and $\hat{P}$ is previously defined.[4]

In the many studies utilizing equilibrium displacement models (e.g., Okrent and Alston, 2012; Pendell et al., 2010; Unnevehr, Gómez, and Garcia, 1998; Weaber and Lusk, 2010; Wohlgenant, 1993), typical interest is in projecting the change in equilibrium price and quantity given a set of anticipated shocks, $\delta$ and $\lambda$. The predicted equilibrium outcomes are obtained by setting (5) equal to (6), and solving, which yields:

(7) $\hat{P} = \frac{\delta-\lambda}{\varepsilon-\eta}$, and

(8) $\hat{Q} = \frac{\delta\varepsilon-\eta\lambda}{\varepsilon-\eta}$.

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[3] Rather than specifying the demand shock to represent the horizontal shift in quantity demanded, it is sometimes useful to re-write the shock as a proportionate change in consumers' willingness-to-pay. This is readily accomplished by solving equation (1) for the change in price: $\hat{P} = \frac{1}{\eta}\hat{Q}^D - \frac{\delta}{\eta}$. Seen in this way, a shock of $-\frac{\delta}{\eta}$ in the price direction (i.e., a $-\frac{\delta}{\eta}$ change in consumer's willingness-to-pay for a given quantity) has the same effect as a shock of $\delta$ in the quantity direction (i.e., a $\delta$ change in consumers' quantity demanded at a given price).

[4] As before, it is possible to equivalently express the shock in the price direction (i.e., a change in marginal cost) as $-\frac{\lambda}{\varepsilon}$.

However, we are interested in this model for a different reason than predicting new equilibrium outcomes. That is, it is often the case that one can observe changes in equilibrium prices and quantities, and we wish to know the extent the observed changes were caused by supply or demand shocks. That is, given data on $\hat{Q}$ and $\hat{P}$, what is $\delta$ and $\lambda$? The question is easily answered by re-writing equations (5) and (6) in terms of the shocks and assuming the market is in equilibrium by setting $\hat{Q} = \hat{Q}^S = \hat{Q}^D$:

(5') $\delta = \hat{Q} - \eta\hat{P}$, and

(6') $\lambda = \hat{Q} - \varepsilon\hat{P}$.

Note that $\hat{P}$ and $\hat{Q}$ are easily calculated using observed data: $\hat{P} = (P_t - P_0)/P_0$ and $\hat{Q} = (Q_t - Q_0)/Q_0$.

There is a direct relationship between $\delta$ and $\lambda$ and the previously discussed demand and supply indicies. To see this, expand (5'):

(9) $\delta = \frac{Q_t - Q_0}{Q_0} - \eta\hat{P}$.

Multiplying both sides by $Q_0$ and re-arranging yields:

(10) $Q_t = Q_0(1 + \eta\hat{P}) + Q_0\delta$.

Noting that $Q_0\left(1 + \eta\hat{P}\right) = Q_t^{e(D)}$, equation (10) can be re-written as:

(11) $Q_t = Q_t^{e(D)} + Q_0\delta$ or $Q_t^{e(D)} = Q_t - Q_0\delta$.

Now, dividing both sides by $Q_t$ and inverting yields:

(12) $Q_t/Q_t^{e(D)} = Q_t/(Q_t - Q_0\delta)$.

The left-hand side is the demand index shown in equation (2), which implies:

(13) $I^{D,Q} = \left(\frac{Q_t}{Q_t^{e(D)}}\right)100 = \left(\frac{Q_t}{Q_t - Q_0\delta}\right)100$.

Equation (13) makes clear that there is a direct relationship between the structural demand shock in an equilibrium displacement model, $\delta$, and the demand index, $I^{D,Q}$, although the relationship is nonlinear. However, if there is a small change in quantity between time period *t* and 0, then $\frac{Q_t}{Q_t - Q_0\delta} \approx \frac{1}{1-\delta}$. A first order Taylor-series approximation to this expression, assuming small $\delta$, further indicates $\frac{Q_t}{Q_t - Q_0\delta} \approx \frac{1}{1-\delta} \approx 1 + \delta$. Thus, for small changes (13) can be written as:

$$(14) \quad I^{D,Q} = \left(\frac{Q_t}{Q_t^{e(D)}}\right)100 = \left(\frac{Q_t}{Q_t - Q_0\delta}\right)100 \approx (1+\delta)100.$$

Thus, a demand index value of $I^{D,Q} = 101$ suggests a proportionate demand shift of approximately $\delta$ =0.01. Equation (13) shows the relationship between the index, $I^{D,Q}$, and the structural demand shock parameter, $\delta$. Re-writing this equation in terms of the demand shock reveals the equivalent relationships:

$$(15) \quad \delta = \frac{Q_t - Q_t^{e(D)}}{Q_0} = \frac{Q_t(I^D/100-1)}{Q_0 I^D/100} = \frac{Q_t}{Q_0}\left(1 - \frac{1}{I^{D,Q}/100}\right).$$

The relationship between the supply index and the supply shock, $\lambda$, can be analogously derived as:

$$(16) \quad \lambda = \frac{Q_t - Q_t^{e(S)}}{Q_0} = \frac{Q_t}{Q_0}\left(1 - \frac{1}{I^{S,Q}/100}\right).$$

The relationships in (15) and (16) are useful because once one is in possession of $\hat{Q}$, $\hat{P}$, $\delta$, and $\lambda$ (all of which are easily calculated from observed price and quantity data in equilibrium as shown above), it is straightforward to calculate welfare changes. As shown by Wohlgenant (2011), changes in consumer and producer surplus when going from time 0 to time *t* are, respectively, given by:

$$(17) \quad \Delta CS = -P^0 Q^0\left(\hat{P} + \frac{\delta}{\eta}\right)(1 + 0.5\hat{Q})$$

$$(18) \quad \Delta PS = P^0 Q^0\left(\hat{P} + \frac{\lambda}{\varepsilon}\right)(1 + 0.5\hat{Q}),$$

where $P^0$ and $Q^0$ are the price and quantity at the initial equilibrium, making $P^0 Q^0$ total revenue/expenditures for the good in question at the initial equilibrium.

**Application 1: Trends in Beef Cattle Supply, Demand, and Welfare**

Given the common use of demand indicies for beef, the first application focuses on this sector. Typical demand indicies focus on per-capita beef consumption (or, rather, per-capita disappearance); however, because of our interest in comparing supply and demand indicies, and in calculating welfare, we move upsteam in the supply chain and focus on the market for fed cattle. This means that producer surplus includes gains or losses to feedlots, stockers, cow calf operators, and suppliers of inputs to these sectors, and consumer surplus includes gains or losses to packers, retailers, and final consumers both domestic and abroad (Just, Hueth, and Schmitz, 2005). It is conceptually possible to separately calculate demand/supply indicies and welfare for each segment of the supply chain, but this would require elasticity estimates at each segment. The demand indicies reported here utilize total quantities, rather than per-capita values, implying that measured increases in demand are partially explained by population growth. Although evaluation of checkoff programs, for example, might warrant determination of demand enhancement effects net the effect of population, from a producer's bottom-line perspective it is likely immaterial whether demand growth is caused by changes in population or other factors such as income or exports. As such, this application focuses on aggregate rather than per-capita quantity measures.

*Data*

Quantity data consist of the total live weight of fed cattle slaughtered in a year. USDA data on average steer and heifer liveweights and on total number of animals slaughtered are obtained from the Livestock Marketing Information Center (LMIC) from 1950 to 2018; total liveweight is calculated as the product of average live cattle weight and the total number of cattle. Corresponding historical price data consist of a combination of datasets from the LMIC primarily consisting of the Nebraska (mainly Omaha) direct fed steer price up until 1990, after which the annual average of the monthly weighted average direct slaughter, five area (Texas/Oklahoma/New Mexico; Kansas; Nebraska; Colorado; Iowa/Minnesota feedlots) series is used. Prices are adjusted for inflation using the GDP deflator from the Bureau of Economic Analysis. The own-price elasticity of supply for fed cattle was assumed to be 0.12 (Suh and Moss, 2017) and the own-price elasticity of demand for fed cattle was assumed to equal -0.56, the beef demand elasticity used in Bekkerman, Brester, and Tonsor's (2019).

*Results*

Figure 2 shows the long run trend in the supply quantity index and the demand quantity index for fed cattle. In 2018, the demand index value was 202, meaning demand was (202-100) = 102% higher than was the case in 1950. The demand index trended positively from 1950 through the mid 1970s. The demand index peaked at a value of 204 in 1976, and it hasn't been as high since. Demand fell through the 1980s and early 1990s before rebounding. Since 2010, the demand index has been at values just below the 1970's peak.

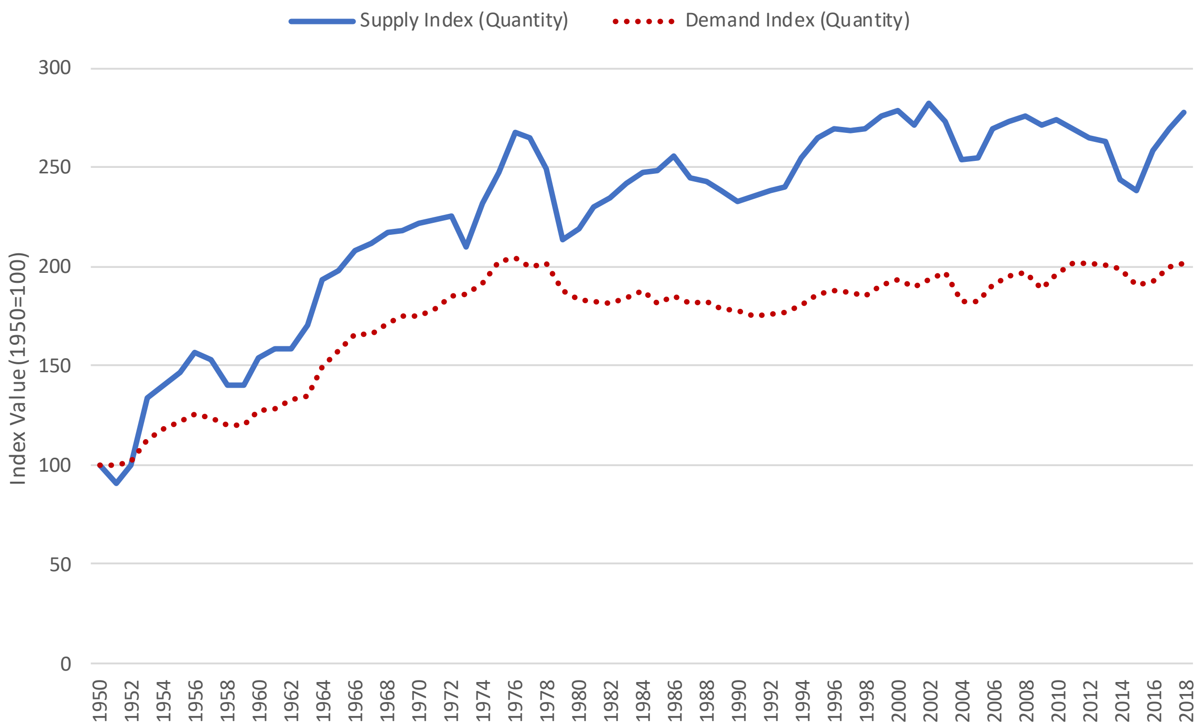


**Figure 2**. Fed Cattle Supply and Demand Quantity Indicies (1950=100)

In 2018, the supply index value was 278, meaning supply was (278-100) = 178% higher than was the case in 1950. The supply index trend was positive from 1950 up till about 2000, but has been stagnant except for the past couple decades. Nonetheless, the 2018 supply index value is the highest of the entire time period since 1950.

Figure 2 shows a significant drop in the supply index that began in 2013 and bottomed out in 2015, which is likely a result of drought in the great plains and from high feed prices. The fact that the supply index dropped during this period while the demand index remained relatively flat helps provide insight into the debate discussed at the beginning of this paper; the reduction in beef consumption at this time appears to have been primarily a result of supply rather than demand factors.

Figure 3 focuses in on the more recent time period since the 1980s and, for illustrative purposes, compares price and quantity quantity indices. The demand quantity index and the demand price (or willingness-to-pay) index generally track one another, although the price index is more volatile, consistent with the findings of Bekkerman, Brester, and Tonsor's (2019). Both demand indicies indicate demand for beef cattle is higher in 2018 than in 1980. Figure 3 also shows the supply quantity index and the supply price (or marginal cost) index. By construction, these two indicies are inversely related. A lower marginal cost implies producers will be willing to sell more at a given output price. Results indicate the marginal costs of producing fed cattle in 2018 is (100-23) = 77% lower than in 1980.

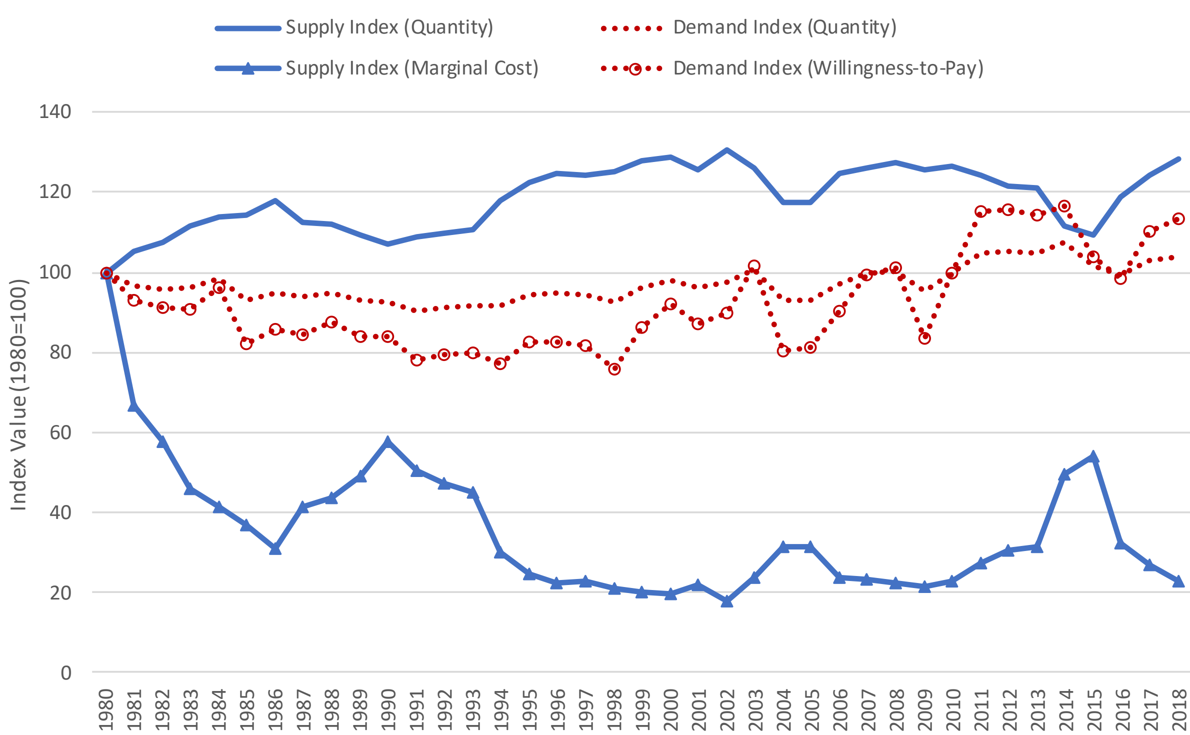


**Figure 3**. Fed Cattle Supply and Demand Indicies (1980=100)

Rather than calculating an index relative to a fixed base year such as 1950 or 1980, it may be useful to focus on year-to-year changes, particularly when calculating welfare measures arising from equilibrium displacement models, which assume "small" changes. Figure 4 shows the annual implied supply and demand shocks from the equilibrium displacement model outlined in equations (5) and (6). Figure 4 shows annual supply shifts being mostly positive since 1980, with a few large negative deviations in 1987, 2004, and 2014. Over this 39-year time period, 64% of the annual supply shocks have been positive and 36% have been negative. From 1980 to 2018, the annual horizontal supply shift has averaged 0.72% of the previous year's quantity. Figure 4 shows that there has been more annual volatility in demand shocks. From 1980 to 2018, demand has increased in only 49% of the years, while falling 51% of the time.

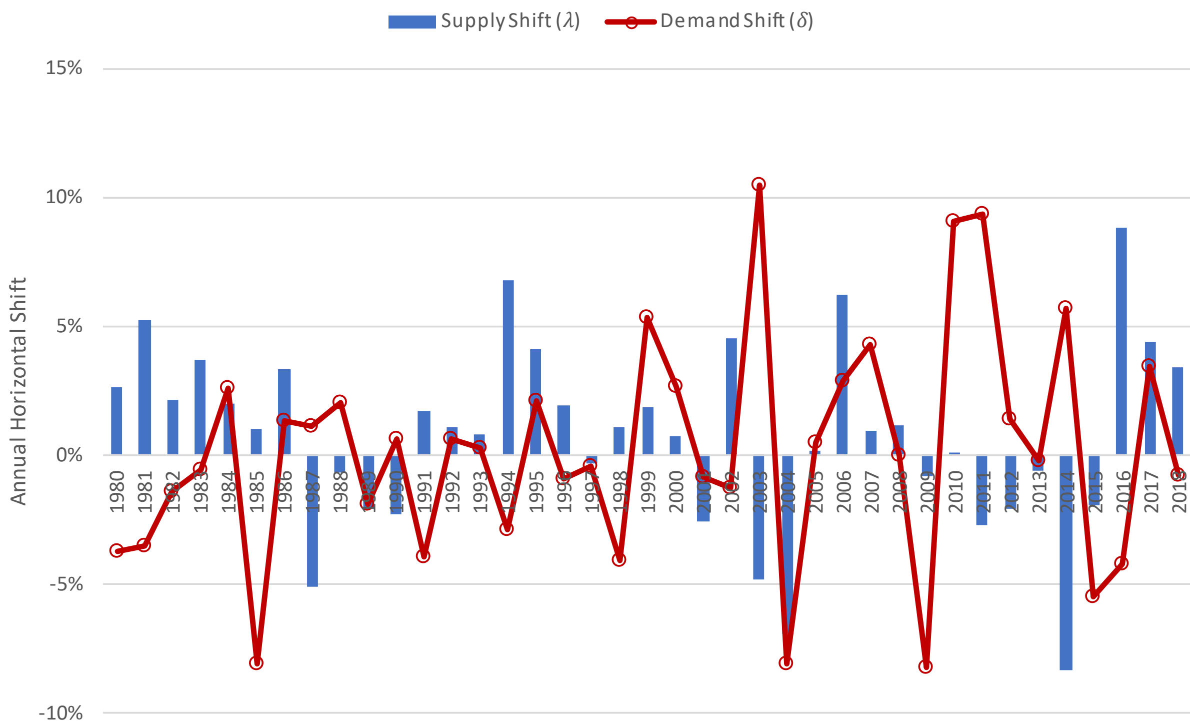


**Figure 4**. Annual Horizontal Shifts in Fed Cattle Supply and Demand Curves

Figure 5 utilizes the estimates of δ and λ shown in figure 4 to calculate producer and consumer surplus changes using equations (17) and (18). On average, from 1980 to 2018, producer surplus increased $2.7 billion each year and consumer surplus increased $0.58 billion each year. Despite these averages, figure 5 shows a high degree of year-to-year variability. The largest annual change in producer surplus was $34 billion from 2015 to 2016; the largest decline in producer surplus was -$28 billion from 2013 to 2014. These are sizeable welfare changes. For context, total fed cattle revenue was $52 billion in 2018. The magnitude of the producer welfare changes results, in part, from the assumed inelasticity of the supply curve. Inelastic supply has been routinely observed in the literature, but it highlights the fact that the welfare changes in figure 5 are most reflective of short-run annual changes where producers do not have time to fully adapt. To further illustrate how the supply shocks results in significant welfare changes, note that the horizontal supply shock from 2015 to 2016 was $\lambda$=0.088 (i.e., an 8.8% supply shock in the quantity direction). Given an own-price elasticity of supply of 0.12, this translates into a 0.088/0.12 = 0.73 vertical shock (i.e., a 73% supply shock in the price direction), which is the input to the producer surplus calculation in equation (18). The change in consumer surplus is less volatile than the producer surplus changes and ranges from a high of $7 billion from 2015 to 2016 to a low of -$6 billion from 2013 to 2014.

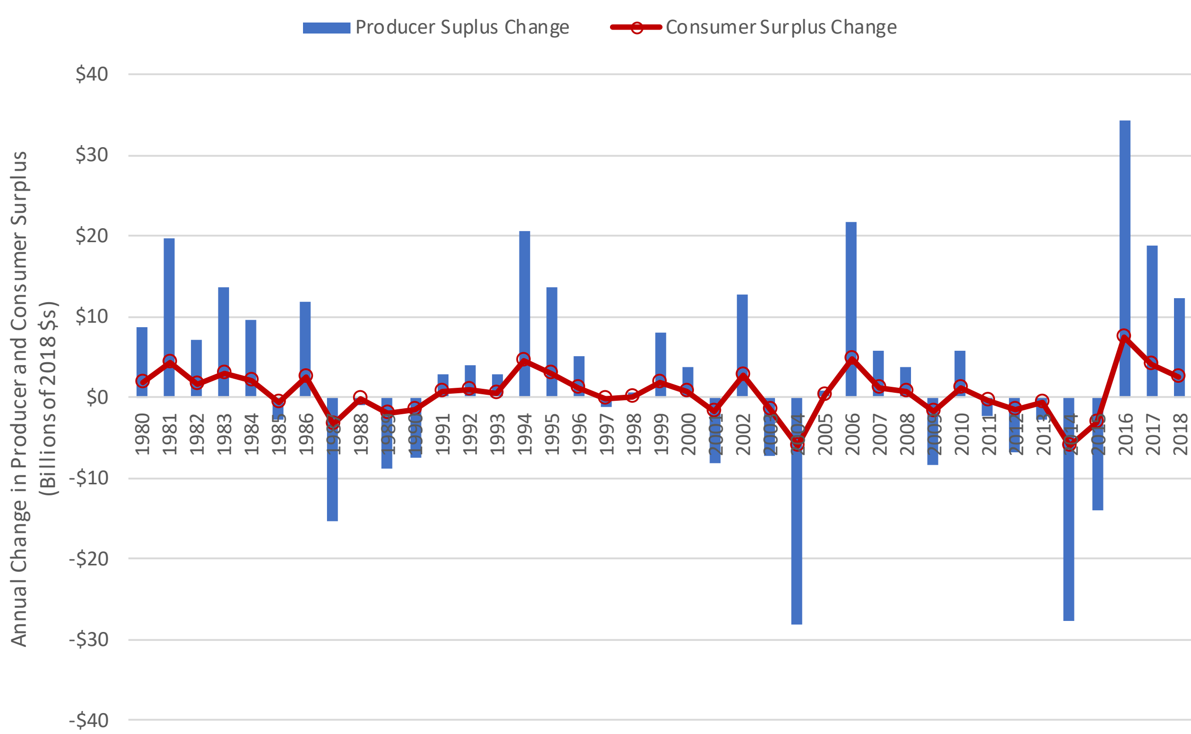


**Figure 5**. Annual Change in Producer and Consumer Surplus (Billions of 2018 $s)

**Application 2: Comparison of Cattle, Hogs, and Chicken**

Beef competes against pork, chicken, and other industries to supply protein for consumers' dinner plates. As such, this section expands the first application to include hogs and chicken. Further analysis of these three sectors is also motivated by the aforementioned reductions in beef demand in the 1980's and 1990's. There was a large literature during that time exploring whether the demand reduction was a result of changes in relative prices or preferences (e.g., Chavas, 1983; Chalfant and Alston, 1988; Eales and Unnevehr, 1993; Moschini and Meilke, 1989). While our analysis doesn't directly answer this question, exploring supply and demand indices for these competing proteins can help provide additional insights into the market dynamics over the past several decades.

*Data*

This section makes use of the same beef cattle data described above. Total live-weight of pork produced in a year was determined using USDA data complied by the LMIC on commercial pork production (average hog live weight times number of hogs slaughtered). The 230-240lb Iowa-Minnesota live hog prices were used until 1989, after which the 51-52% lean hogs barrows and gilt price average price was used. Given that there are no live broiler prices consistently reported over time, the analysis of the chicken market necessarily moves one step downstream in the supply chain. Total annual chicken meat production was obtained from USDA World Supply and Demand Estimate reports, and the 12 city national composite USDA chicken price was obtained from LMIC. All prices are adjusted for inflation using the BEA GDP deflator. Analysis makes use of the supply elasticities reported by Suh and Moss (2017), which were 0.12, 0.15, and 0.06

for beef, pork, and chicken. Demand elasticities, -0.57, -0.66, and -0.52 for beef, hogs, and chicken are from Bekkerman, Brester, and Tonsor (2019).

*Results*

Figure 6 reports fed cattle, hog, and chicken quantity supply indicies from 1980 to 2018. Clearly, chicken supply shifts have far outpaced that for hogs or cattle. The 2018 chicken supply index value is 380, meaning chicken supply is (380-100) = 280% higher than in 1980. By contrast, hog and beef supply are only 66% and 28% higher, respectively, than in 1980. These differences are likely explained by differential productivity patterns in these sectors. The rise in hog productivity since 2000 corresponds with a time period over which the industry became increasingly vertically integrated, increasingly mirroring the broiler chicken sector. The much longer biological production lags in beef cattle (which range from two to three years from the time a breeding decision is made until harvest) and less integrated nature of the beef cattle industry help explain the smaller increases in the supply index in this sector as compared to pork and chicken.

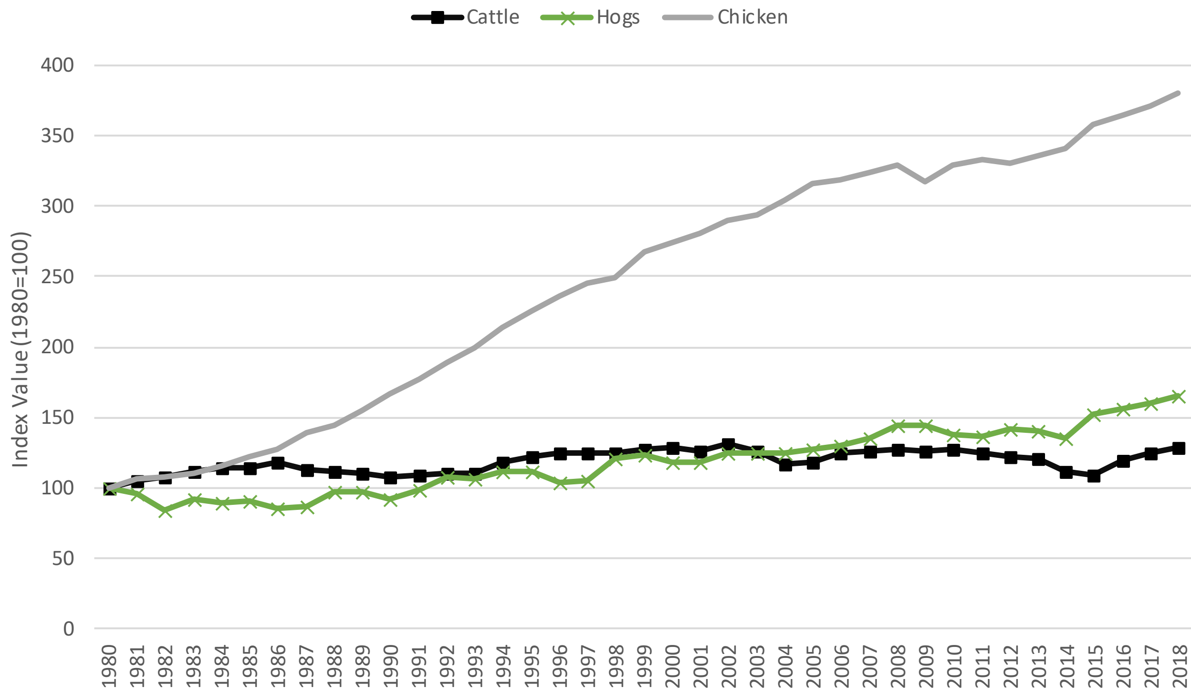


**Figure 6**. Fed Cattle, Hog, and Chicken Quantity Supply Quantity Indicies (1980=100)

Figure 7 reports demand indices for cattle, hogs, and chicken. Chicken demand is 233% higher in 2018 than in 1980. By contrast, pork and beef demand were only 11% and 4% higher in 2018 than in 1980. Comparing figures 6 and 7 shows that the rise in per-capita chicken consumption that occurred over the last couple decades was not only due to falling chicken prices brought about by increasing productivity gains, but that chicken demand also significantly increased, perhaps due to increasing concerns about fat and cholesterol. The fact that beef and pork demand did not rise significantly over this time period is notable given that the U.S. population increased more than 100 million people (a 44% rise) and the U.S. economy significantly expanded from 1980 to 2018.

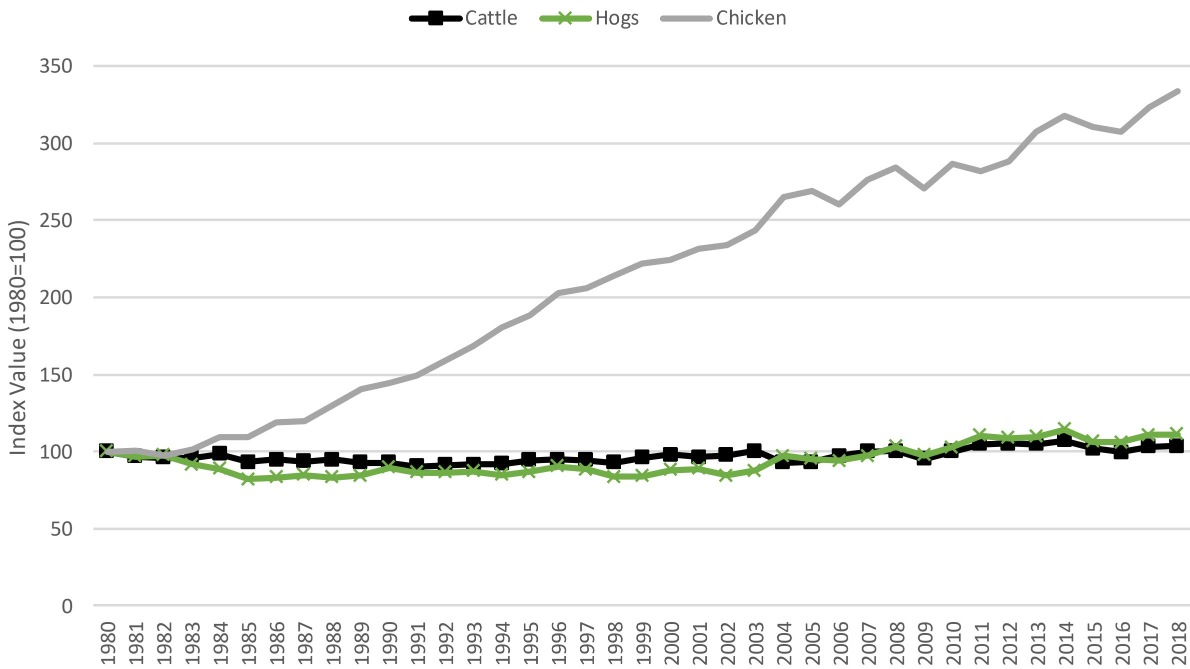


**Figure 7**. Fed Cattle, Hog, and Chicken Quantity Demand Quantity Indicies (1980=100)

To help provide a validity check for the supply and demand indicies, correlations with the indicies and other economic variables were calculated. Table 1 shows that supply indicies for cattle, hogs, and chicken are all negatively correlated with corn prices, as would be expected, given the prevalent use of corn as livestock and poultry feed. Supply indicies for each animal species are each positively correlated with the Palmer Drought Severity Index, which is smaller in drier weather and larger in wetter weather. The USDA ERS calculates aggregate TFP changes for the agricultural sector. While their TFP measures aggregate all agricultural outputs, exploring its relationship with the supply indices for beef, pork, and chicken is of interest. As shown in table 1, the correlations are all large and positive as hypothesized.

**Table 1**. Correlations among Cattle, Hog, and Chicken Supply and Demand Indicies and Other Variables Potentially affecting Supply or Demand (1980 to 2018)

| Variable | Cattle | Hogs | Chicken |
|---|---|---|---|
| | *Supply Quantity Indicies* | | |
| Real Price of Corn[a] | -0.36 | -0.15 | -0.29 |
| Drought Severity Index[b] | 0.21 | 0.28 | 0.27 |
| U.S. Agriculture Total Factor Productivity[c] | 0.66 | 0.91 | 0.97 |
| | *Demand Quantity Indicies* | | |
| Real U.S. Gross Domestic Product[d] | 0.64 | 0.69 | 0.99 |
| U.S. Unemployment Rate[e] | 0.06 | 0.15 | -0.32 |
| U.S. Dollar Exchange Rate with Canadian Dollar[f] | -0.39 | -0.60 | -0.20 |
| U.S. Dollar Exchange Rate with Japanese Yen[f] | -0.22 | -0.27 | -0.76 |

Note: correlations greater than 0.32 and 0.27 in absolute value are significantly different than zero at the 0.05 and 0.10 levels, respectively.
[a]Data are prices received ($/bu) by farmers reported by USDA-National Agricultural Statistical Service adjusted for inflation by the GDP deflator from the Bureau of Economic Analysis.
[b]Data are the annual Palmer Drought Severity Index (smaller numbers indicate drier weather; larger numbers indicate wetter weather) calculated by NOAA and reported by the EPA Climate Change Indicators (the last available data is 2015).
[c]Data is overall U.S. agriculture total factor productivity calculated by the USDA Economic Research Service (the last available data is 2015).
[d]Annual Gross Domestic Product data for the U.S. is obtained from the Bureau of Economic Analysis (BEA) and is deflated with the BEA GDP deflator.
[e]Data are U.S. Unemployment Rate reported by the Bureau of Labor Statistics for residents age 16 and older).
[f]Annual average exchange rate are obtained from the Organization of Economic Cooperation and Development and currencies are expressed relative to the U.S. dollar (i.e., larger numbers represent a stronger U.S. dollar).

Table 1 also shows correlations between the animal demand indicies and variables anticipated to affect demand. The correlations are all of intuitive sign except, perhaps, the correlations with the unemployment rate, which are small and insignificant for cattle and hogs. Only for chicken did rising unemployment result in lower meat demand. A rising U.S. dollar makes U.S. animal products more expensive for foreigners, and as shown in table 1, this translates into lower demand.

**Application 3: County-Level Corn Supply Indicies**

One of the challenges of the most widely used TFP measures is that they are typically aggregated over many commodities and are aggregated over many geographic regions. There is interest, however, in more disaggregated changes in productivity and supply conditions. As such, this section explores changes in county-level supply quantity indicies for corn. This application is partially motivated by the high interest in recent years in corn yields and the relationship between yield and weather, climate, and other factors (e.g., Lusk, Tack, and Hendricks, 2018; Ortiz-Bobea and Tack, 2018; Schlenker, and Roberts, 2009). Moreover, previous work has linked state-level aggregate TFP measures with changing climatic conditions (Ortiz-Bobea, Knippenberg, and Chambers, 2018), an approach that could be extended to specific commodities and counties using the supply indicies discussed here.

*Data*

Data on county-level corn production from 1980 to 2018 (in bushels) and state-level farm prices received (in $/bushel) are obtained from USDA-NASS. Counties with fewer than 20 years of observations were removed from the sample. Given that a number of counties were missing data in 2018, the maps shown below report the average supply quantity index values over the last three years in the sample, 2016-2018. A corn supply elasticity of 0.29 is assumed based on the estimates in Hendricks, Smith, and Sumner, (2014); the value is similar to the global corn supply elasticity estimate of 0.27 found by Roberts and Schlenker (2013).

*Results*

Figure 8 shows variation in the corn supply quantity indicies in 2016-2018 compared to 1980 across the United States. There is marked heterogeneity across the U.S., with some counties having supply index values of over 500 in 2016-18 and others having negative values. Counties with the largest supply shifts since 1980 are clustered in the Dakotas, Kansas, Missouri, and the Mississippi Delta. Counties in North Carolina and Ohio had negative supply shocks in 2016-18 relative to 1980.

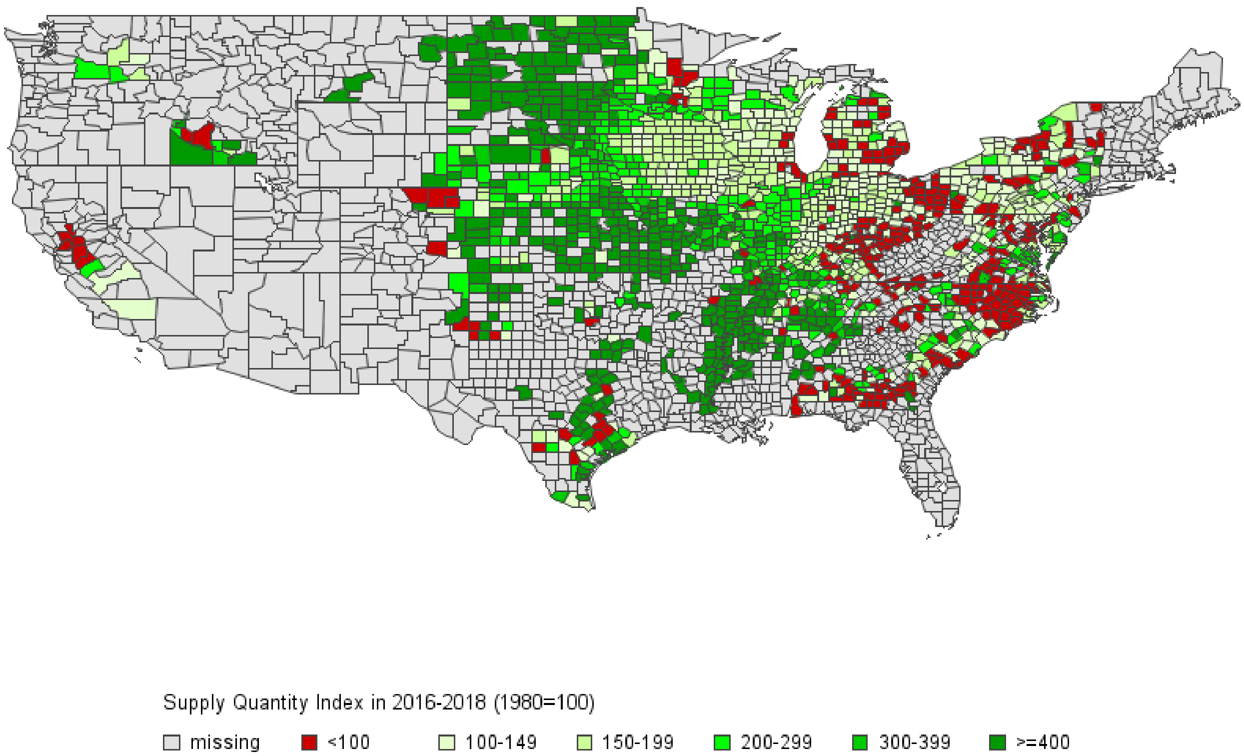


**Figure 8**. County-Level Corn Supply Quantity Indicies in 2016-2018 Compared to 1980

While the map in figure 8 shows heterogeneity across the U.S. at a point in time relative to 1980, it does not convey information about the overall trend during the intervening time period. Figure 7 shows the median county supply index in each year from 1980 to 2018, and for illustrative purposes, trends in supply indicies for the counties with the highest level of corn production in 1980 (Kossuth, Iowa) and in 2018 (McLean, Illinois). Trends were positive for all three measures, but there was significant year-to-year volatility. Highlighting the importance of heterogeneity, the figure shows, for example, that the impact of the 2012 drought caused a much larger negative supply shock in McLean Illinios than in Kossuth, Iowa.

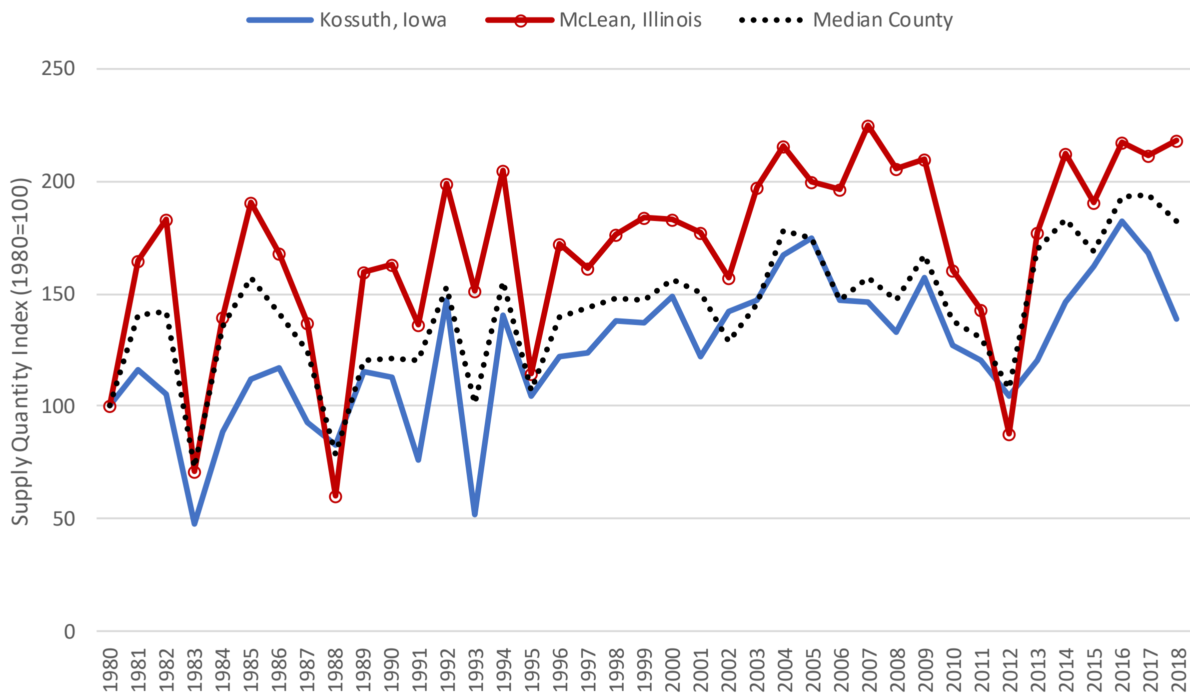


**Figure 9**. Corn Supply Quantity Indicies over Time in Highest Producing U.S. Counties in 1980 and 2018 and the Median County in Each Year

Figure 10 focuses in on the more recent period and shows a map of county-level supply indices in 2016-18 relative to the year 2000. Perhaps surprisingly, many areas of Ohio, Indiana, and southern Illinois have experienced negative corn supply shocks in 2016-2018 relative to 2000. The expanded geographical area of U.S. corn production (e.g more acres in the Dakotas) over this period helped mitigate national corn market effects of the adverse Eastern Cornbelt supply shocks. This example demonstrates the benefits of refined county-level supply indices and the economic welfare insights that follow for many commodity markets.

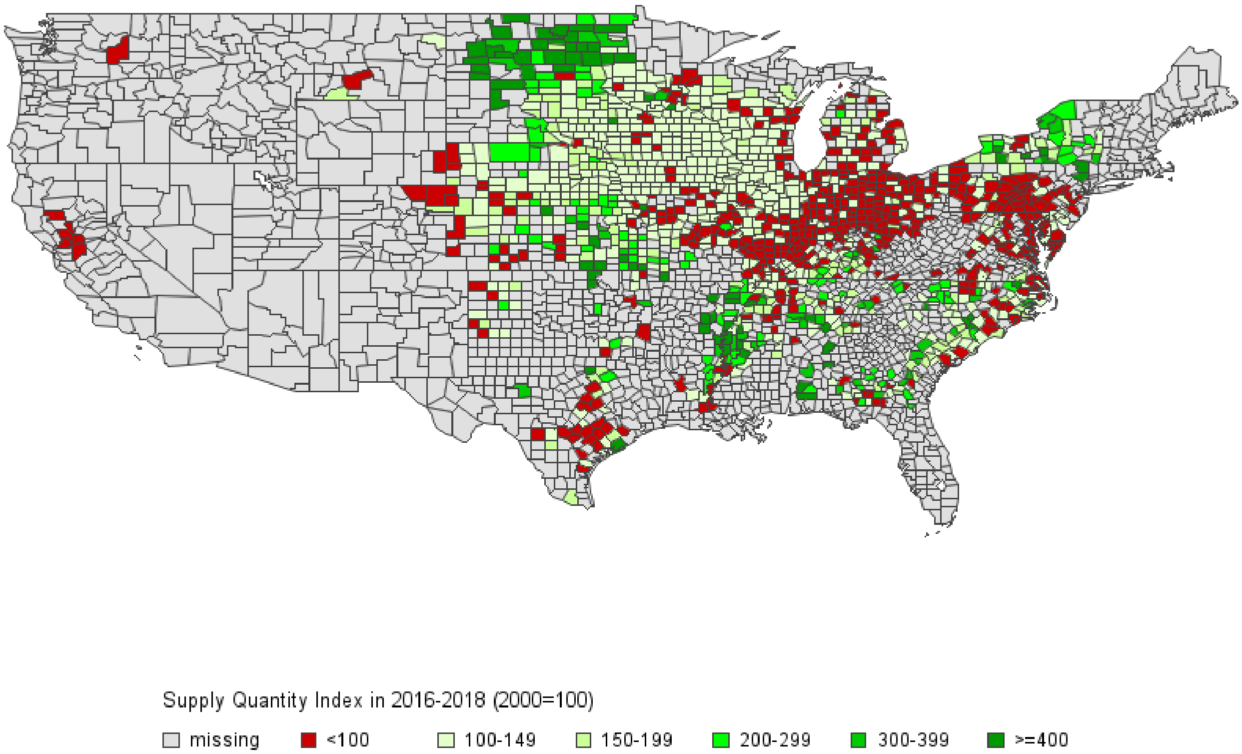


**Figure 10**. County-Level Corn Supply Quantity Indicies in 2016-2018 Compared to 2000

## Conclusion

There is high demand for economic analysis and insight related to agriculture. Globally, the wide array and overlapping nature of complex societal grand challenges such as climate change, animal welfare, environmental impacts, sustainability, and food security elevate interests in economic insights beyond mere commercial interests. At the same time, many traditional agricultural industries continue to internally struggle with controversial issues such as market concentration, effectiveness of checkoff programs, asymmetric price transmission, declining farmer's share of retail receipts, etc. that also can benefit from economic insight. Economists and industry analysts could benefit from new and better tools to quickly and effectively provide insights to help address key questions associated with these challenges.

Many U.S. commodity markets are monitored by USDA and other governmental agencies, resulting in readily available historical databases characterizing market price and quantity movements. Changes in prices and quantities over time reflect adjustments in supply and demand conditions that are often confounded and are the source of much controversy. This highlights the need to clearly identify changes in supply and demand, which are not directly observable, from available price and quantity data.

This paper introduced new supply indices and, in conjunction with demand indices, demonstrated how to determine welfare changes so as to enable enhanced economic understanding of changing market conditions. There is a long academic literature using structural models to predict how a hypothesized supply or demand shock will affect future equilibrium prices, quantities, and welfare. This paper, in a sense, inverts this common practice, and shows how to use changes in equilibrium prices and quantities to back out the implied supply and demand shocks and their welfare consequences. We illustrated the practicality and use of supply and demand indicies in three applications, highlighting the economic insights that this approach yields. Greater utilization of the tools outlined in this article might enable economists to more effectively engage in discussions around grand societal challenges and inner-industry debates, and might result in improved decision making via the use of better economic insights.

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