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Modeling Beef Quality Heterogeneity

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The effects of various supply and demand shifts on beef price, quantity, and industry welfare have been widely studied under the assumption of beef quality homogeneity. In this paper, we construct a model of the beef sector that incorporates differences in beef quality. The model is used to analyze the effect of supply and demand shifts on changes in prices and quantities of high- and low-quality beef and changes in revenue accruing to producers of high- and low-quality beef. Model results indicate that supply and demand shocks have the potential to alter the average quality of beef on the market and the price premium charged for high-quality beef, which has important implications for retailers selling quality-differentiated beef and producers selling cattle on a grid.

Key Words: beef, equilibrium displacement model, multisector model, quality heterogeneity

JEL Classification: Q11, Q18

Several studies have analyzed the effect of technology-induced supply shifts or consumer-driven demand shifts on beef industry welfare (e.g., Mullen, Wohlgenant, and Farris; Unnevehr, Gomez, and Garcia; Wohlgenant 1993). In addition, several studies have focused on whether beef producers gain more from advertising or research into cost-saving technologies (Chung and Kaiser; Wohlgenant 1993, 1999). One notable theme among such studies is that beef was treated as a homogeneous commodity and no distinction was made between changes in prices or quantities of beef of different qualities.

Although beef quality homogeneity might have been a realistic assumption in the past, today's market for beef is segregated by the USDA quality grading system. In the late 1980s, less than 10% of graded beef was assigned a quality grade lower than Choice. However, by 2000, almost 40% of graded beef received a grade lower than Choice. Despite such changes in quality differentiation within the grading system, little research has focused on identifying elasticities of demand or supply for differing beef qualities or determining the effect of supply and demand shocks on prices and quantities of different beef qualities.

Given the heterogeneity in today's marketplace, consumers have the ability to substitute between differing qualities of beef.[1] To a

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[1] Although most consumers are unfamiliar with the terms "Choice" and "Select," taste panel research indicates consumers prefer the taste of Choice to Select beef (Lorenzen et al.). The current USDA grading system, although imperfect, appears to transmit some information about quality as evidenced by the facts that most fed cattle are voluntarily graded and that significant price premiums for Choice over Select are often observed in the market.

somewhat lesser extent, feedlots and fed cattle producers also have the ability to substitute between cattle qualities by varying the number of days cattle are on feed (see Greer and Trapp) or by altering the types of cattle purchased for feeding. These facts suggest that homogeneous quality models might not provide an accurate picture of price, quantity, or revenue changes occurring for a good comprised of different qualities.

When quality homogeneity is assumed, no inferences can be made about the effect of exogenous shocks on the average quality of beef and the premium for higher quality beef. This is problematic for a number of reasons. First, supply or demand shifts might be invoked with the use of funds from producer-financed programs such as a checkoff program. Producer-financed promotion might not have an equivalent effect on prices and quantities of high- and low-quality beef, implying that benefits might not be equally distributed across producers.[2] Second, beef retailers and fed cattle producers are increasingly interested in beef quality and the effects of exogenous shifts on quantity levels and price premiums. Grocery stores are beginning to offer a diversity of beef products in addition to the traditional selection of Select or store-brand beef. These retailers are interested in how new regulations, for example, might change the price premiums they can charge for high-quality beef products. At the farm level, Schroeder et al. projected that by 2006, over 60% of fed cattle would be marketed on a grid, in which cattle are priced on the basis of quality characteristics. McDonald and Schroeder showed that the distribution of cattle quality had a significant effect on profitability of marketing on a grid, and Schroeder and Graff showed that changes in the Choice-to-Select spread had a significant effect on the variability of grid revenues. Clearly, cattle producers would benefit from knowing how factors such as increased promotion, new food safety concerns, or new technology might affect price premiums for quality.

The goal of this paper is threefold. First, we develop a model that is able to capture quality heterogeneity in retail, wholesale, and farm markets. Our model is a hybrid of the product-differentiated model of James and Alston and the marketing channel model of Wohlgenant (1993). Second, the model is implemented with data from the beef sector to analyze how generic promotion and research affects beef quality and how the revenues generated by such shocks are allocated among high- and low-quality producers. Finally, we identify the key parameters affecting beef quality and price premium changes in an effort to guide future empirical work.

A Model of Heterogeneous Beef Quality

To accurately model the effect of supply and demand shocks on beef quality, a number of factors must be considered. First, at the retail sector, large markets exist for both high- and low-quality beef, and generic promotion is aimed at expanding these two markets. However, even if promotion expands the market for all beef, the expansion might be biased toward a particular quality. For example, high-quality producers might receive a higher return from the "Beef: It's What's For Dinner Campaign" than low-quality producers or vice versa. As a result, a model must be able to incorporate asymmetries in effects of promotion across quality. In addition, the model must be able to capture the ability of consumers to substitute between qualities of beef.

An accurate model of the beef sector must also be able to incorporate the fact that consumers purchase a bundle, consisting of raw beef and other marketing inputs, when purchasing beef. The greater the substitutability between raw beef and marketing inputs, the less retail demand shocks will be transmitted to the farm sector. Furthermore, it is possible that the elasticity of substitution between beef and marketing inputs differs for high- and low-quality beef.

Finally, the model must be able to capture

[2] For present purposes, we abstract away from measuring welfare changes. In the conclusions of the paper, we discuss how our model might be extended to accurately calculate welfare changes associated with factors of production used in producing high- and low-quality beef.

the ability of producers to transform cattle quality and potential asymmetries in the effect of a supply shock on quality. For example, low-quality cattle can often be transformed into higher quality cattle by increasing the number of days on feed. Furthermore, new technologies are likely to have more of an effect on low-quality cattle (e.g., Bos Indicus breeds) that can be raised in less hospitable environments and give producers a wide range of inputs than on higher quality cattle.

The model proposed by Wohlgenant (1993) is flexible, in that it accounts for substitution between raw beef and marketing inputs, but is not flexible enough to account for beef quality heterogeneity. Thus, we combine the Wohlgenant (1993) model with the product-differentiated model of James and Alston. The result is a quality-differentiated, multistage equilibrium displacement model. Our model is characterized by a horizontal linkage between high- and low-quality beef at each marketing level, in addition to a vertical linkage of retail, wholesale, and farm markets. The model also allows for the possibility of substitution between meat products and marketing services, which, as shown by Wohlgenant (1993) and Mullen, Wohlgenant, and Farris, can have significant effects on the predictions of models based on vertical linkages between farm and retail sectors.

The following is a description of the heterogeneous beef market model. Beef is grouped by quality according to whether it grades USDA Choice or higher (hereafter, Choice) or USDA Select or lower (hereafter, Select). A long-run competitive equilibrium is assumed with constant returns to scale at the wholesale and retail levels.[3]

Retail Market

At the retail level, consumer demand for each beef quality depends on its own price as well as the price of the competing quality. Assuming that these two qualities compose a weakly separable group, demand for the two qualities can be characterized in terms of the overall elasticity of demand for beef, η. Following James and Alston, consumer demand for Choice and Select beef can be written as

$$(1) \quad \hat{Q}_C^R = (\gamma_C S_C^R \eta - \sigma_{CS}^R S_{CS}^R)\hat{P}_C^R + S_S^R(\sigma_{CS}^R + \gamma_C \eta)\hat{P}_S^R - \delta\gamma_C\eta,$$

$$(2) \quad \hat{Q}_S^R = \underbrace{(\gamma_S S_S^R \eta - \sigma_{CS}^R S_C^R)\,\hat{P}_S^R}_{\text{Demand curve slope}} + \underbrace{S_C^R(\sigma_{CS}^R + \gamma_S \eta)\,\hat{P}_C^R}_{\text{Cross-price effect}} - \underbrace{\delta\gamma_S\,\eta}_{\text{Demand shock}},$$

where $\hat{Q}_C^R$ and $\hat{Q}_S^R$ are percent changes in quantity demanded of retail Choice and Select beef, respectively (i.e., $\hat{X} = d \ln X = dX/X$); $\hat{P}_C^R$ and $\hat{P}_S^R$ are percent changes in the retail price of Choice and Select beef, respectively; σ_{CS}^R is the Allen elasticity of substitution between Choice and Select beef for the consumer; γ_C is the expenditure expansion elasticity for Choice beef (the percent change in quantity demand of Choice beef resulting from a 1% change in total beef expenditures); S_C^R is the expenditure share for Choice beef (consumer expenditures on Choice beef divided by expenditures on all beef); and δ is the percent change in initial equilibrium price because of an exogenous demand shift (e.g., an increase in consumer willingness to pay for the initial quantity of beef as a result of promotion). Adding up conditions requires that $S_C^R\gamma_C + S_S^R\gamma_S = 1$ and $S_C^R + S_S^R = 1$. The parameter γ_{CS}^R captures the ability of consumers to substitute between different beef qualities. This formulation assumes that aggregate beef demand is increased by δ, and that the demand shock is distributed to the different qualities through model parameters. It is relatively easy to show that introducing the demand shock in this manner is identical to the multiple good case in Wohlgenant (1993), in which demand shocks are assumed to be

[3] More detail on model development is available from the authors on request. Beef imports are ignored, whereas export markets are assumed to be captured in the consumer demand equations.

identical across products.[4] It is worthwhile to note that underlying own- and cross-price demand elasticities for Choice and Select beef can be recovered through elasticity decompositions described in James and Alston. For example, the own-price elasticity of demand for Choice beef is $S_C^R\gamma_C\eta - S_C^R\gamma_{CS}^R$.

Following Wohlgenant, the (inverse) retail supply of each retail beef quality can be determined by adding the marketing margins to the wholesale supply curves, as shown in Equations (3) and (4):

$$(3)\quad \hat{P}_C^R = S_C^W\hat{P}_C^W,$$

$$(4)\quad \hat{P}_S^R = S_S^W\hat{P}_S^W.$$

In Equation (3), S_C^W is the cost share of wholesale Choice beef and $\hat{P}_C^W$ is the percent change in the price of wholesale Choice beef. The notation in Equation (4) is similar, except the subscript "C" for Choice beef is replaced with the subscript "S" for Select beef. Equations (3) and (4) assume that the supply of marketing services is perfectly elastic (i.e., $\hat{P}_M^W = 0$).

Wholesale Market

The wholesale market for beef is characterized by the derived demand for wholesale beef from meat retailers, such as grocery stores and restaurants, and the supply of wholesale beef by beef packers. Following Wohlgenant (1993), derived demand equations for wholesale Choice and Select beef are

$$(5)\quad \hat{Q}_C^W = -\sigma_{CM}^W(1 - S_C^W)\hat{P}_C^W + \hat{Q}_C^R,$$

$$(6)\quad \hat{Q}_S^W = -\sigma_{SM}^W(1 - S_S^W)\hat{P}_S^W + \hat{Q}_S^R,$$

where $\hat{Q}_C^R$ is the change in the equilibrium retail Choice quantity and σ_{CM}^W is the Allen elasticity of substitution between Choice beef and marketing services used to produce retail Choice beef.[5] The greater the value of σ_{CM}^W, the higher degree of substitutability between beef and marketing inputs, implying that retail demand shocks will have a relatively smaller influence on the farm price of Choice cattle. The rest of the notation is similar to that in the retail market, except that the superscript "R," denoting retail, is replaced with "W," denoting wholesale. These equations are based on a model by Diewert (1971, 1981) that assumes a long-run competitive equilibrium and constant returns to scale technology. The elasticity of substitution between Choice and Select beef is not present in Equations (5) or (6) because of the constant returns to scale assumption invoked by Diewert. With constant returns to scale, additional retail facilities identical to the existing facilities can easily be built as firms enter the market or expand. So long as free entry and the replication of existing technologies are not constrained, the production of one grade can easily expand without limiting the production of the other grade, and so the elasticity of substitution effect that would exist because of capacity constraints is not present. This does not imply zero substitution possibilities in the model, only that substitution between qualities is a result of consumer preferences, farm supply, or both, and not capacity constraints by the packer or retailer.

Similarly at the retail level, the (inverse) supply of each wholesale beef quality can be determined by adding the marketing margin to the farm supply curves as shown in Equations (7) and (8):

$$(7)\quad \hat{P}_C^W = S_C^F\hat{P}_C^F,$$

$$(8)\quad \hat{P}_S^W = S_S^F\hat{P}_S^F.$$

Again, these equations assume that the supply of marketing services at the farm level is perfectly elastic (i.e., $\hat{P}_M^F = 0$). Here the superscript "F" denotes farm- or feedlot-level prices and shares.

[4] The incorporation of quality-specific shocks would be a straightforward extension of the model. If δ_C and δ_S are the shocks to Choice and Select, respectively, the latter part of Equation (1), labeled "demand shock," $-\delta\gamma_C\eta$, would be replaced with the term: $-\gamma_C\eta(\delta_C S_C^R + \delta_S S_S^R) + S_S^R\sigma_{CS}^R(\delta_C - \delta_S)$.

[5] The Allen elasticity of substitution is appropriate in this case because there are only two inputs. The inputs for retail Choice beef production are wholesale Choice beef and marketing services, whereas the inputs for retail Select beef are wholesale Select beef and marketing services.

Farm Market

The farm market is characterized by the derived demand for cattle, which is derived from beef packers and the supply of cattle by feedlots and other fed cattle producers. The derived demand for Choice and Select cattle at the farm level are very similar to that for wholesale beef:

$$\text{(9)} \quad \hat{Q}_C^F = -\sigma_{CM}^F(1 - S_C^F)\hat{P}_C^F + \hat{Q}_C^W,$$

$$\text{(10)} \quad \hat{Q}_S^F = -\sigma_{SM}^F(1 - S_S^F)\hat{P}_S^F + \hat{Q}_S^W.$$

The terms in Equations (9) and (10) are similar to the terms at the wholesale level, except that the superscript "W" denoting wholesale level is replaced by "F" for the farm or feedlot level. As was the case for the beef retailer, constant returns to scale and free entry implies no capacity constraints for slaughtering and processing plants in the long run, so the derived demand equations at the farm level do not contain an elasticity of substitution between Choice and Select beef.

To complete the model, we need two primary supply curves from feedlots and fed cattle producers. As shown by James and Alston, these supply curves are given by

$$\text{(11)} \quad \hat{Q}_C^F = (\rho_C\varepsilon S_C^F - \tau_{CS}^F S_S^F)\hat{P}_C^F + S_S^F(\tau_{CS}^F + \rho_C\varepsilon)\hat{P}_S^F + \lambda\rho_C\varepsilon,$$

$$\text{(12)} \quad \hat{Q}_S^F = \underbrace{(\rho_S\varepsilon S_S^F - \tau_{CS}^F S_C^F)\hat{P}_S^F}_{\text{Supply curve slope}} + \underbrace{S_C^F(\tau_{CS}^F + \rho_S\varepsilon)\hat{P}_C^F}_{\text{Cross-price effect}} + \underbrace{\lambda\rho_S\varepsilon}_{\text{Supply shock}},$$

where Q_C^F denotes the quantity of Choice cattle supplied, ε is the overall own-price elasticity of cattle supply, τ_{CS}^F is the elasticity of substitution (transformation) between Choice and Select cattle, ρ_C is the percent change in Choice cattle supplied when the supply of all cattle increases by 1%, and λ represents a supply shock denoting the percent decrease in marginal cost of cattle production at the initial equilibrium. An adding-up condition requires that $S_C^F\rho_C + S_S^F\rho_S = 1$. As with the retail demand equations, it is possible to identify the own- and cross-price supply elasticities for Choice and Select beef (see James and Alston). For example, the own-price supply elasticity for Choice beef is $S_C^R\rho_C\varepsilon - S_S^R\tau_{CS}^R$. For the remainder of the paper, we will use the term "producer" to represent feedlots and other fed cattle producers.

Model Solution

Equations (1) through (12) completely characterize the retail, wholesale, and farm markets for Choice and Select beef. The model consists of 12 endogenous variables and 12 market-clearing conditions.[6] The only exogenous variables in the model are the demand and supply shocks: δ and λ. The other variables in Equations (1) through (12) represent structural parameters of the system. To solve for changes in endogenous variables, we define the following 12 by 1 matrix,

$$\text{(13)} \quad \mathbf{Y} = \begin{pmatrix} \hat{Q}_C^R \\ \hat{Q}_S^R \\ \hat{Q}_C^W \\ \hat{Q}_S^W \\ \hat{Q}_C^F \\ \hat{Q}_S^F \\ \hat{P}_C^R \\ \hat{P}_S^R \\ \hat{P}_C^W \\ \hat{P}_S^W \\ \hat{P}_C^F \\ \hat{P}_S^F \end{pmatrix},$$

which comprises the endogenous variables of the system. The parameters defining the relationships between endogenous variables are placed in a 12 by 12 matrix, β, such that in the absence of shocks $\beta\mathbf{Y}$ equals a vector of zeros when markets clear. Now, a 12 by 1 vector $\mathbf{X}$ is defined that comprises exogenous sup-

[6] The endogenous variables are two prices and two quantities for each quality grade at the retail, wholesale, and farm level.

ply and demand shocks. Given the specified parameter values and a given supply or demand shock, the values in Equation (13) are determined by calculating $\mathbf{Y} = \beta^{-1}\mathbf{X}$.

Imposing Quality Homogeneity

The model described above is used to determine the effect of exogenous demand and supply shocks on prices and quantities of high- and low-quality beef. It is useful to compare this model to a more traditional model that assumes beef quality homogeneity. Fortunately, the model formulation provides a convenient way of imposing quality homogeneity. The model outlined in Equations (1) through (12) collapses to a homogeneous quality model when the following restrictions are imposed.

- In Equations (1) and (2), $\sigma^{R}_{CS} = 0$.
- In Equations (1) and (2), $\gamma_C = \gamma_S = 1$.
- In Equations (3) and (4), $S^{W}_{C} = S^{W}_{S}$.
- In Equations (5) and (6), $\sigma^{W}_{CM} = \sigma^{W}_{SM}$.
- In Equations (7) and (8), $S^{F}_{C} = S^{F}_{S}$.
- In Equations (9) and (10), $\sigma^{F}_{CM} = \sigma^{F}_{SM}$.
- In Equations (11) and (12), $\tau^{F}_{CS} = 0$.
- In Equations (11) and (12), $\rho_C = \rho_S = 1$.

The assumption of fixed proportions can also be imposed by restricting $\sigma^{F}_{CM} = \sigma^{F}_{SM} = \sigma^{W}_{CM} = \sigma^{W}_{SM} = 0$.

Analysis

The model is analyzed under a demand shock, such as that caused by promotion, or a supply shock, such as that resulting from research reducing the marginal cost of cattle production. For the supply shock, the marginal cost of cattle production is assumed to fall by 10% (relative to the initial equilibrium price) and leave demand unchanged (i.e., $\lambda = 0.10$ and $\delta = 0$). In the second case, we increase demand by 10%, as might be caused by promotion, and leave supply unchanged. That is, for the second case, we set $\lambda = 0$ and $\delta = 0.10$ and solve the above system. These two cases are useful for determining effects of promotion and cost-reducing research on the beef sector. One could also analyze downward shifts in demand, such as might be caused by a food safety scare, or upward shifts in supply, such as might be caused by a regulation, by simply reversing the sign on λ and δ. The choice of a 10% shock is somewhat arbitrary, but it is consistent with other supply and demand shocks analyzed in extant literature. For example, Wohlgenant (1993) analyzed the effect of a 10% supply shock; Freebairn, Davis, and Edwards analyzed the effect of a 10% reduction in cost of nonfarm inputs; and Lemieux and Wohlgenant used supply shocks ranging from 4% to 19% and demand shocks ranging from 0% to 4%. Proportionally increasing (decreasing) the size of the demand or supply shock simply increases (decreases) the estimated changes in endogenous variables in a proportional manner.[7]

Effects of Supply and Demand Shocks on Quality

A model of homogeneous quality implicitly assumes that a given supply or demand shock has the same effect on all qualities. As a result, a homogeneous quality model predicts no change in the average quality resulting from an exogenous shock. However, in a heterogeneous quality model, the quantity of the higher quality good could increase more than the lower quality good, or vice versa, causing a change in the average quality of beef on the market. Following James and Alston, we define the change in average quality at the *j*th market level as the difference in percent changes in the quantities of Choice and Select beef: $\Delta Quality^{j} = \hat{Q}^{j}_{(B)C} - \hat{Q}^{j}_{(B)S}$. Similarly, a change in the price premium for higher quality meat at the *j*th market level can be defined as: $\Delta Premium^{j} = \hat{P}^{j}_{(B)C} - \hat{P}^{j}_{(B)S}$. There are a number of instances in which it might be important to determine the magnitude of average quality or price premium changes. For example, more cattle are being marketed on a grid basis, in

[7] Although the supply and demand shocks are equivalent in percentage terms, the demand shock will have a larger effect on results because a 10% shock at the retail level represents a larger shock in absolute terms than an equivalent percentage shock at the farm level.

which cattle grading Choice or higher receive premiums and cattle grading Select and lower receive discounts. A change in the price premium for Choice implies a change in the Choice-to-Select price spread, which has been shown to be a significant determinant of the value of sorting cattle to sell by alternative marketing methods (Schroeder and Graff), the value of ultrasound technology (Lusk et al., 2003), and the value of keeping animals on feed (Greer and Trapp). In addition, by determining a change in average quality, inferences might be drawn about the effect of an exogenous shock on beef sales to restaurants, which typically sell at least Choice quality beef versus sales to grocery stores, which typically sell Select or ungraded beef.

We are interested in differences generated by homogeneous and heterogeneous quality models for a given supply or demand shock. By observing the magnitudes of $\Delta Quality$ and $\Delta Premium$, we can determine a weakness associated with assuming quality homogeneity, which imposes the following restriction $\Delta Quality = 0$ and $\Delta Premium = 0$. As a further comparison, we use the estimated changes in endogenous variables to predict changes in revenue at the farm level. By construction of the model, a heterogeneous quality model will generate very similar estimates of total changes in beef revenue compared with a model imposing quality homogeneity. Of interest here, however, is how revenue changes are distributed across producers and consumers of different qualities.

Data and Model Parameters

To empirically determine effects of supply and demand shocks on beef quantities and prices, the model outlined in Equations (1) through (12) requires parameterization. In the following, we specify three different sets of parameters corresponding to three different levels of heterogeneity. The first model assumes beef is of a homogeneous quality and is referred to as the *UNIFORM* model. The second assumes beef heterogeneity and is appropriately named the *DIFF* model for "differentiation." The third model assumes greater differentiation and is referred to as the *DIFF2* model. To provide clarity into the effects associated with heterogeneous versus homogeneous models, we hold all share values and elasticities of substitution between beef and marketing inputs constant across the three model formulations.

One of the advantages of the model developed in this paper is that empirical estimates exist for many of the model parameters, and even where estimates are not readily available, many of the parameters are of known sign. For example, USDA data can be used to determine relevant ranges for most of the cost and expenditure shares. The aggregate own-price retail demand elasticity, own-price farm supply elasticity, and elasticity of substitution between beef and marketing services are taken from previously published studies. We use available wholesale-level data on prices and quantities of Choice and Select beef to draw inferences about the elasticity of substitution between Choice and Select beef. The only parameters for which there are relatively little available data are the expansion elasticities. However, intuition and previously published studies provide guidance regarding the magnitude of these parameters.

USDA price spread data were used to determine beef and marketing input cost shares at each marketing level. Data reported by the USDA/ERS indicate that in 2002, the farmers' share of the wholesale beef dollar was about 80% and the wholesalers' share of the beef retail dollar was roughly 55%. We assume these share values were identical for both qualities in all three models.

Data from the Livestock Marketing Information Center (LMIC) were used to determine the share of Choice versus Select beef sold in 2002. Data indicate that over 13.1 billion pounds of beef was graded Choice or higher in 2002, and roughly 8 billion pounds of beef was graded Select or Standard in 2002. During this same time period, the price of Choice boxed beef averaged \$115.09/cwt and the price of Select boxed beef averaged \$108.97/cwt. These data imply that the revenue/cost shares of Choice and Select beef were roughly 65% and 35%, respectively, in 2002. Because no comparable data exists at the farm or retail level, we assigned both expenditure shares at the retail level and cost shares at the farm level to 65% for Choice beef and 35% for Select beef in all three models.

Now that all share values have been assigned, we move to determining the elasticity parameters. We set the own-price elasticity of demand for beef at the retail level to −0.56, which was the value estimated by Brester and Schroeder. This value is also very similar to that generated by Eales and Unnevehr (1993) (i.e., −0.57). Following Wohlgenant (1993) and Unnevehr, Gomez, and Garcia, we use an own-price farm supply elasticity of 0.15. Wohlgenant (1989) found that the elasticity of substitution between beef and marketing services at the wholesale level was 0.72. With this estimate as a baseline, we assigned the elasticities of substitution between beef and marketing services at both the wholesale and farm levels to 0.70 for all three models. It is worthwhile to note that an elasticity of substitution between beef and marketing inputs that exceeds the absolute value of the own-price elasticity of demand implies meat producers will generally lose from marketing research.

To provide a feel for the degree of substitutability between Choice and Select beef, we use the wholesale data (boxed beef prices and slaughter quantities) in Lusk et al. (2001). McFadden showed that the elasticity of substitution between two goods could be determined by regressing the log ratio of the quantities of two goods against a constant and the log ratio of the prices of the two goods, in which the coefficient on the price ratio is the elasticity of substitution between the two goods (note: this specification is derived from a CES utility function). We applied this framework to the monthly data set of 150 observations from 1987 to 1999 in Lusk et al. (2001) and found

$$(14)\quad \log(Q_C^{ADS}/Q_S^{ADS}) = \underset{(19.08)}{0.417} + \underset{(7.74)}{2.657}\log(P_S^{BXB}/P_C^{BXB}) \qquad R^2 = 0.29,$$

where Q_i^{ADS} are average daily slaughter quantities of Choice and Select beef in millions of pounds, P_i^{BXB} are Choice and Select boxed prices ($/cwt), trend is a trend variable, and numbers in parentheses below coefficient estimates are *t*-statistics. These estimates imply an elasticity of substitution between Choice and Select beef of about 2.7. Because these data are at the wholesale level and substitutability is likely higher at the retail level, we assumed that the elasticity of substitution between Choice and Select beef was 4 in *DIFF*. In *DIFF2*, we assigned the elasticity of substitution to 1 to reflect more quality differentiation and therefore less substitutability. As was the case at the retail level, no data or previous estimates exist to determine the elasticity of substitution or transformation between Choice and Select beef at the farm level. Intuitively, this value is likely to be smaller than at the retail level because it is more difficult, for example, to transform Select cattle into Choice than it is for the consumer to simply alter a consumption decision. Nevertheless, there likely is some degree of substitutability at the farm level. Feedlots can feed Select animals longer to achieve the Choice quality grade, or in the longer run, they can alter the types of animals they purchase to change quality. For *DIFF* and *DIFF2*, we used an elasticity of substitution of −1.5 and −1, respectively.

Finally, we must determine values for expansion elasticities. James and Alston argue that the expansion elasticity should be greater for the higher quality good than for the lower quality good at the retail level, with the opposite being the case at the farm level. Their intuition is likely to hold in our case as well. First, consider the farm-level expansion elasticities. If total beef production increases, say, from an increase in demand, it seems likely that Select quantity supplied would increase more than Choice because feedlots can sell animals earlier than they normally would to meet the increase in demand. If cattle were sold early, feedlots would not give animals the feeding time necessary to reach the Choice quality grade. Low-quality cattle can also be raised in a larger range of environments, which makes the entry-exit effect greater. As such, for *DIFF* we set the supply expansion elasticity for Choice at 0.8, which implies a supply expansion elasticity for Select of 1.37. For the *DIFF2* model, these values were changed to 0.5 and 1.93, respectively, to reflect greater diversity among beef qualities.

To gain insight into magnitude of the retail expenditure expansion elasticities, we examined the estimates reported in Lusk et al. (2001), who reported wholesale demand estimates for Choice and Select beef and allowed for seasonal demand shifts. Assuming that the second and third quarters of the year (Spring and Summer) reflect heightened demand for beef because of cook-outs, barbecues, etc., we can investigate how Choice relative to Select beef demand changes as demand (which serves as a proxy for expenditures) increases during the Spring and Summer. The most general model reported in Lusk et al. (2001) shows that the seasonal dummy shifters are greater for Choice beef for both quarters 2 and 3 than they are for Select beef. Furthermore, the seasonal dummy shifter is highly significant for Choice beef in quarter 2 but is not significant for Select in quarters 2 or 3. These results imply that as demand increases (which would likely increase expenditures), Choice beef increases more than Select. For *DIFF,* we set the expenditure expansion elasticity for Choice beef at 1.2, which implies an expenditure expansion elasticity for Select beef of 0.63. These values are changed to 1.4 and 0.26, respectively, in *DIFF2*. Indirect support for a larger expansion elasticity for high-quality beef than low-quality beef is given by Eales and Unnevehr (1988), who found that the expenditure elasticity for table-cut beef was greater than that for ground beef (1.565 vs. −1.573), and by Brester and Wohlgenant, who found that the income elasticity of demand for fed beef exceeded that for nonfed beef (1.869 vs. −1.933).

Monte Carlo Analysis of Effects of Model Parameters on Quality

Although the above approach is useful for determining the range of potential effects, each of the models is based on specific parameter values, and as such, it is difficult to draw generalizations about the effect of model parameters on resulting estimates. In their analytical analysis, James and Alston showed that the signs of $\Delta Quality^j$ and $\Delta Premium^j$ are generally ambiguous and depend on magnitudes of selected parameters. Given that our model is more complex than that in James and Alston, analytical model solutions are not likely to provide much clarity into the effects of model parameters on changes in quality. As a result, we conduct a Monte Carlo analysis to determine the effect of model parameters on changes in quality and price premiums. The Monte Carlo experiment also provides insight into the potential bounds on quality changes and price premiums given the selected parameter distributions.

The Monte Carlo experiment was conducted as follows. Step 1: Variables S_i^j, η, and ε were assigned values identical to that shown in Table 1. Step 2: Values for variables σ_{CS}^R, γ_C, τ_{CS}^F, ρ_C, and σ_{iM}^j were randomly drawn from uniform distributions with the following respective bounds: [1, 4], [1, 0.5], [−2, 1], [0.5, 1.5], and [0.5, 0.85]. These bounds correspond to the high and low values in the *DIFF* and *DIFF2* models in Table 1. Step 3: Values for γ_S and ρ_S were determined with the adding-up conditions. Step 4: If analysis focused on the supply shock, then λ was assigned the value 0.10 and δ was set to zero. If analysis focused on the demand shock, then δ was assigned the value 0.10 and λ was set equal to zero. Step 5: The model was solved and solutions for endogenous changes in prices and quantities were stored. Step 6: Steps 1 though 5 were repeated 4,000 times with new random draws at each iteration. Finally, we calculated $\Delta Quality^j$ and $\Delta Premium^j$ for each Monte Carlo iteration for j = R, W, and F.

To summarize the results of the experiment, we estimated the following linear regressions at the retail, wholesale, and farm levels,

$$(15)\quad \Delta Quality = \beta_0 + \beta_1\sigma_{CS}^R + \beta_2\gamma_C\ \beta_3\tau_{CS}^F + \beta_4\rho_C + \sum_{j=W,F}\sum_{i=C,S}\beta_{ij}\sigma_{iM}^j,$$

Table 1. Model Parameters and Definitions

Parameter	Definition	Source	*UNIFORM* Model	*DIFF* Model	*DIFF2* Model
S_C^R	Expenditure share of Choice beef	USDA 2002	0.65	0.65	0.65
S_S^R	Expenditure share of Select beef	$S_S^R = 1 - S_C^R$	0.35	0.35	0.35
η	Own-price retail demand elasticity of beef	Brester and Schroeder	−0.56	−0.56	−0.56
σ_{CS}^R	Elasticity of substitution between Choice and Select beef	Econometric estimate and intuition	0.00	4.00	1.00
γ_C	Expenditure expansion elasticity for Choice beef	Lusk et al. (2001) and intuition	1.00	1.20	1.40
γ_S	Expenditure expansion elasticity for Select beef	$\gamma_S = (1 - \gamma_C S_C^R)/S_S^R$	1.00	0.63	0.26
S_C^W	Cost share of Choice beef for beef retailer	USDA 2002	0.55	0.55	0.55
S_S^W	Cost share of Select beef for beef retailer	USDA 2002	0.55	0.55	0.55
σ_{CM}^W	Elasticity of substitution between Choice beef and marketing inputs	Wohlgenant (1989) and intuition	0.70	0.70	0.70
σ_{SM}^W	Elasticity of substitution between Select beef and marketing inputs	Wohlgenant (1989) and intuition	0.70	0.70	0.70
S_C^F	Cost share of Choice beef for beef packer	USDA 2002	0.80	0.80	0.80
S_S^F	Cost share of Select beef for beef packer	USDA 2002	0.80	0.80	0.80
σ_{CM}^F	Elasticity of substitution between Choice beef and marketing inputs	Wohlgenant (1989) and intuition	0.70	0.70	0.70
σ_{SM}^F	Elasticity of substitution between Select beef and marketing inputs	Wohlgenant (1989) and intuition	0.70	0.70	0.70
S_C^F	Cost share of Choice beef at farm level	USDA 2002	0.65	0.65	0.65
S_S^F	Cost share of Select beef at farm level	$S_S^F = 1 - S_C^F$	0.35	0.35	0.35
τ_{CS}^F	Elasticity of substitution between Choice and Select beef	Guestimate	0.00	−1.5	−1.00
ε	Own-price farm supply elasticity of beef	Value used in Wohlgenant (1993)	0.15	0.15	0.15
ρ_C	Supply expansion elasticity for Choice beef	Intuition	1.00	0.80	0.50
ρ_S	Supply expansion elasticity for Select beef	$\rho_S = (1 - \rho_C S_C^F)/S_S^F$	1.00	1.37	1.93

Table 2. Change in Prices and Quantities due to an Upward Shift in Beef Demand[a]

	Percent Change in Variables[b]		
Variable	*UNIFORM* Model	*DIFF* Model	*DIFF2* Model
Percent change in endogenous variables			
Q^{R}_{C}	3.850	4.146	4.892
Q^{R}_{S}	3.850	3.300	1.914
Q^{W}_{C}	2.060	2.288	2.817
Q^{W}_{S}	2.060	1.636	0.654
Q^{F}_{C}	1.065	1.256	1.664
Q^{F}_{S}	1.065	0.711	−0.046
P^{R}_{C}	3.125	3.244	3.623
P^{R}_{S}	3.125	2.905	2.201
P^{W}_{C}	5.682	5.898	6.587
P^{W}_{C}	5.682	5.282	4.002
P^{F}_{C}	7.103	7.372	8.234
P^{F}_{S}	7.103	6.603	5.002
Percent change in revenue at farm level			
Choice beef	8.244	8.721	10.035
Select beef	8.244	7.361	4.953
Total revenue	8.244	8.245	8.257

[a] Based on a 10% reduction in marginal cost of beef relative to initial price.
[b] *DIFF* allows some heterogeneity in beef quality, *DIFF2* allows greater heterogeneity in quality, and *UNIFORM* assumes beef is a homogeneous good.

$$(16) \quad \Delta Premium = \beta_0 + \beta_1\sigma^{R}_{CS} + \beta_2\gamma_C + \beta_3\tau^{F}_{CS} + \beta_4\rho_C + \sum_{j=W,F}\sum_{i=C,S}\beta_{ij}7\sigma^{j}_{iM}.$$

Results

Effects of the supply shock on prices, quantities, and farm revenue are shown in Table 2. Results clearly demonstrate the importance of accounting for beef heterogeneity, as the *UNIFORM* model predicts identical changes for prices and quantities of Choice and Select beef at all marketing levels. Results indicate that the outward shift in supply causes farm price (quantity) to decrease (increase) more for Select than for Choice. The intuition behind such a result lies in the implicit supply parameters for the two beef qualities (own-price supply elasticity of Select is more elastic than for Choice). In general, a parallel outward supply shift will reduce price more in a market with a more elastic supply curve, which is the Select market in this case. In the new equilibrium, the large price reduction for both beef qualities outweighs the relatively small quantity increase to result in a fall in total revenues. Interestingly, changes in total revenue are very similar across the three models. In contrast, the distribution of revenue across high and low quality is quite different between models.

Table 2 reports the effect of a demand shock in the *DIFF, DIFF2,* and *UNIFORM* models. From a revenue enhancement standpoint, the demand shock benefits Choice producers more compared with Select producers. Although total revenues increase for both qualities, the farm quantity of Select beef falls. The reason this occurs is because the demand shock has a larger effect on Choice demand than Select demand via the larger expansion elasticity. As a result, the Choice price increase is relatively large and causes the Select supply curve to shift left. The supply curve decreases so much that the new general equilibrium output is lower than before. Again, it is evident that the *UNIFORM* model is unable to provide insight into effects of changes in quality. In terms of farm revenue changes, total revenues are similar across models, but the distribution of revenue gains are quite different, especially for the DIFF2 model.

To provide a better understanding regarding economic significance of employing a homogeneous versus heterogeneous quality model, use the numbers reported in Tables 2 and 3 to calculate changes in revenue caused by the supply and demand shifts. As reported earlier, over 13.14 billion pounds of beef was graded Choice or higher and over 8 billion pounds of beef was graded Select or Standard in 2002, with the prices of Choice and Select boxed beef averaging \$115.09/cwt and \$108.97/cwt, respectively, over the same time period. These statistics imply that total revenue for the wholesale beef sector was about \$23.84 billion in 2002. Data reported in Table 2 imply that a 10% shift in farm supply would decrease total farm revenue. However, this revenue change is not equivalent across models. For example, predicted changes in Select beef revenue are −\$48.8, −\$90.2, and −\$51.3 million for the *DIFF, DIFF2,* and *UNIFORM*

Table 3. Change in Prices, Quantities, and Revenue because of a Downward Shift in Beef Supply[a]

Variable	Percent Change in Variables[b] *UNIFORM* Model	*DIFF* Model	*DIFF2* Model
Percent change in endogenous variables			
Q_C^R	0.469	0.400	0.465
Q_S^R	0.469	0.596	0.475
Q_C^W	0.948	0.857	0.836
Q_S^W	0.948	1.119	1.158
Q_C^F	1.215	1.110	1.041
Q_S^F	1.215	1.409	1.537
P_C^R	−0.837	−0.979	−0.646
P_S^R	−0.837	−0.912	−1.192
P_C^W	−1.522	−1.448	−1.175
P_S^W	−1.522	−1.659	−2.167
P_C^F	−1.903	−1.810	−1.469
P_S^F	−1.903	−2.074	−2.708
Percent change in revenue at farm level			
Choice beef	−0.711	−0.721	−0.443
Select beef	−0.711	−0.694	−1.213
Total revenue	−0.711	−0.711	−0.712

[a] Based on a 10% reduction in marginal cost of beef relative to initial price.
[b] *DIFF* allows some heterogeneity in beef quality, *DIFF2* allows greater heterogeneity in quality, and *UNIFORM* assumes beef is a homogeneous good.

Table 4. Changes in Quality and Price Premium Caused by Supply and Demand Shifts

Variable[a]	% Change *UNIFORM* Model	*DIFF* Model	*DIFF2* Model
10% Supply increase			
$\Delta Quality^R$	0.000	−0.196	−0.010
$\Delta Quality^W$	0.000	−0.262	−0.322
$\Delta Quality^F$	0.000	−0.299	−0.496
$\Delta Premium^R$	0.000	0.116	0.545
$\Delta Premium^W$	0.000	0.211	0.992
$\Delta Premium^F$	0.000	0.263	1.240
10% Demand increase			
$\Delta Quality^R$	0.000	0.846	2.978
$\Delta Quality^W$	0.000	0.652	2.163
$\Delta Quality^F$	0.000	0.545	1.710
$\Delta Premium^R$	0.000	0.338	1.422
$\Delta Premium^W$	0.000	0.615	2.586
$\Delta Premium^F$	0.000	0.769	3.232

[a] $\Delta Quality^j = Q_C^j - Q_S^j$; the percent change in Choice quantity minus the percent change in Select quantity. $\Delta Premium^j = P_C^j - P_S^j$; the percent change in Choice price minus the percent change in Select price.

models, respectively. Differences are more pronounced for the demand shock. For example, predicted changes in Choice beef revenue after the demand shock are \$610.9, \$408.3, and \$685.4 for the *DIFF, DIFF2,* and *UNIFORM* models, respectively. These results indicate that a homogeneous quality model can under- or overpredict changes in revenue accruing to a particular quality by millions of dollars.

The effect of supply and demand shocks on quality and price premiums are reported in Table 4. The supply shock reduces average quality, whereas demand shocks increase it. The effect is more pronounced the greater the degree of beef heterogeneity (i.e., *DIFF* vs *DIFF2*). That the supply shock decreases average quality is consistent with the Alchian-Allen theorem, which posits that an increase in per unit cost for both qualities will increase demand for the higher quality good by decreasing its relative price (Borcherding and Silberberg). Shifting supply outward is similar to reducing per unit cost, which in the Alchian-Allen model would mean an increase in the relative price of Choice versus Select beef, which would make Select relatively more desirable than Choice, decreasing average quality on the market. Quality premiums increase for both supply and demand shocks, but more so for the demand shock. Although quality premiums increase for both supply and demand shifts, the former is with higher prices for both qualities and the latter is with lower prices for both qualities. Importantly, the *UNIFORM* model predicts no change in quality or price premium relative to the heterogeneous quality models.

Are the changes in price premiums and quality large enough to be economically important? The changes in price premiums predicted by *DIFF2* are as high as 1.25% for the supply shock and 3.23% for the demand shock. How do these changes in price premiums compare with changes actually observed in the market? With USDA data from 2001,

Table 5. Effect of Model Parameters on Quality Changes: Results from Monte Carlo Analysis

	% Change in Price Premium[a]			% Change in Quality[b]		
Variable	Farm	Wholesale	Retail	Farm	Wholesale	Retail
10% supply increase						
Constant	0.720	0.576	0.317	−2.376	−2.277	−2.100
σ^{R}_{CS}	−0.001	−0.001	0.000	−0.004	−0.004	−0.004
γ_{C}	0.469	0.375	0.206	0.686	0.749	0.863
τ^{F}_{CS}	0.001	0.001	0.001	−0.008	−0.007	−0.007
ρ_{C}	−1.193	−0.954	−0.525	1.706	1.545	1.256
σ^{W}_{CM}	0.231	0.185	0.102	0.347	0.378	−0.264
σ^{W}_{SM}	−0.236	−0.189	−0.104	−0.345	−0.379	0.262
σ^{F}_{CM}	0.136	0.109	0.060	0.162	−0.207	−0.173
σ^{F}_{SM}	−0.119	−0.095	−0.052	−0.189	0.185	0.151
Model R^2	.97	.97	.97	.97	.97	.95
Mean[c]	0.006	0.005	0.003	−0.004	−0.004	−0.002
10% demand increase						
Constant	−2.714	−2.171	−1.194	−7.012	−7.377	−8.045
σ^{R}_{CS}	−0.002	−0.002	−0.001	−0.012	−0.013	−0.013
γ_{C}	3.755	3.004	1.652	5.517	6.021	6.934
τ^{F}_{CS}	−0.005	−0.004	−0.002	−0.017	−0.016	−0.015
ρ_{C}	−1.073	−0.859	−0.472	1.538	1.394	1.133
σ^{W}_{CM}	−0.965	−0.772	−0.425	−1.352	−1.484	0.890
σ^{W}_{SM}	0.932	0.745	0.410	1.300	1.425	−0.947
σ^{F}_{CM}	−0.466	−0.373	−0.205	−0.760	0.628	0.520
σ^{F}_{SM}	0.549	0.439	0.242	0.779	−0.591	−0.460
Model R^2	.97	.97	.97	.97	.98	.98
Mean[c]	0.012	0.010	0.005	0.017	0.022	0.024

Note: Results from regressions using data from each of the 4,000 Monte Carlo iterations.
Note: All parameter estimates are statistically significant at the $p = .01$ level of lower.
[a] Dependent variable is $\Delta Quality^j = Q^j_C - Q^j_S$.
[b] Dependent variable is $\Delta Premium^j = P^j_C - P^j_S$.
[c] Mean change in quality or price premium across the 4,000 Monte Carlo iterations.

we calculated the difference between weekly price changes in the wholesale price of Choice boxed beef and weekly price changes in the price of Select boxed beef (i.e., we calculated $\Delta Premium$). The average $\Delta Premium$ over this time period was −0.04%, with a standard deviation of 1.22%, a maximum of 2.8%, and a minimum of −3.4%. Assuming the changes are normally distributed, a price premium increase as high as 1.25% would be observed less than 16% of the time, and a price premium increase as high as 3.23% would be observed less than 1% of the time. Thus, the changes in price premiums predicted from the heterogeneous quality model are economically significant in that they represent "large" changes compared with those typically observed from week to week.

To investigate how the parametric assumptions affected results, we conducted a Monte Carlo analysis, and the results are summarized in Table 5. Table 5 reports regression results aimed at identifying the effect of model parameters on price premium and quality changes across 4,000 Monte Carlo iterations. Regarding the supply shock, it is evident that the supply expansion elasticity tends to have a larger effect on changes in price premiums and quality compared with other model parameters. Larger supply expansion elasticities for Choice are associated with smaller changes in average price premium and larger changes in average quality. This occurs because as the supply expansion elasticity for Choice increases, Choice supply becomes more elastic. An increase in the elasticity of Choice supply would mean that Choice price is more responsive to the supply shock than Select, resulting in a decrease in change in price premium. The elasticities of substitution between beef and marketing inputs also have a relatively large effect on results. The regression equations suggest that if both σ^{W}_{CM} and σ^{W}_{SM} increase by 1, the price premium (and average quality at the farm and wholesale levels) will fall. That is, the elasticity of substitution for Select has a larger effect on the price premium than Choice. Regarding the demand shock, the demand expansion elasticity has a relatively large effect on premium and quality changes. The larger the supply expansion effect for Choice, the larger the change in price premium and quality. For the demand shock, the larger the elasticity of substitution between beef and marketing inputs, the less retail demand increases are translated into derived demand increases.

Implications and Conclusions

Modeling beef quality is important to the beef sector for a number of reasons. First, the beef sector is increasingly differentiated by quality at both the retail and farm levels. At the retail level, grocery stores are beginning to sell both higher quality beef cuts such as Certified Angus Beef as well as the traditional selection of Select or store brand beef. Understanding how price premiums change for these products is important for beef retailers. At the farm level, producers are increasingly selling cattle on a grid in which animals are given premiums or discounts based on quality. For example, Schroeder et al. found that cattle feeders only sold 16% of fed cattle on a grid in 1996, but this figure increased to 45% in 2001. When animals are marketed on a grid, changes in prices of high versus low quality, as well as the distribution of quality in a pen, can have significant effects on profitability (McDonald and Schroeder). This issue is also important because of massive amounts of check-off funds spent on promotion. If beef is treated as a homogeneous commodity, it is impossible to assess the effect of potential demand shifts on surplus accrued to producers of high- or low-quality beef. Under the assumptions used in this analysis, we find that outward demand shifts will most likely increase the share of high-quality beef on the market and will increase the price premium charged for higher quality beef.

Our findings indicate that models assuming homogeneous quality will, in some circumstances, provide poor indicators of changes in price premiums and quantity associated with an exogenous shock. Whether future research should incorporate quality heterogeneity depends on the magnitudes of the elasticities of substitution between qualities at the retail and farm levels, as well as potential differences in expansion elasticities for different qualities. Our analysis suggests that if expansion elasticities differ significantly across models, then a homogeneous quality model will likely provide erroneous predictions of changes in quality, price premiums, and distribution of changes in revenue.

Now that a heterogeneous quality model incorporating farm, wholesale, and retail sectors has been constructed, a number of issues warrant future research. Because market-level data are unavailable to determine many of the parameters of interest, future research might focus on finding other means of estimating these parameters. In particular, our analysis suggests that expansion elasticities have a relatively large influence on results, and as such, future work might focus on estimating these parameters. Experimental economics or survey methods could be used to determine how Choice and Select beef demand would expand as overall beef expenditures increase.

Future work might also focus on investigating the effect of quality-specific shocks. For example, promotion might be aimed at increasing high- or low-quality demand. Brester and Schroeder found own- and cross-price effects of branded and generic advertising, and a similar effect might be present for quality-specific advertising. The model developed in this paper can easily be extended to incorporate such effects. The model might also be extended to incorporate the effect of generic advertising versus branded advertising. For example, Crespi and Marette demonstrated that generic promotion could negatively affect producers of a quality differentiated good because generic advertising might cause consumers to view all products similarly, causing substitution from a potentially higher quality, differentiated product to a generic product. Our results suggest that an aggregate increase in demand for beef will increase quality, which runs somewhat counter to the results of Crespi and Marette. Clearly this is an area in need of further investigation.

Another important area for future research relates to measuring the welfare effects of quality changes. Producers of high- and low-quality beef, which pay equivalent per unit fees into the check-off program, are not likely to share equally in the benefits of promotion. Given the results of our models, we could calculate total changes in beef industry welfare by constructing an aggregate revenue or profit function of a representative cattle producer that produced Choice and Select beef with the ability to substitute between the two qualities. However, such an approach could not separately identify welfare for a Choice producer and a Select producer (i.e., they would be one and the same). To accurately discuss welfare, our model would have to be expanded to incorporate factors of production that are not mobile across Choice and Select producers (e.g., high- and low-quality genetics). Then, welfare accruing to those independent factors of production could be calculated. Although our model does not trace price changes back to factors of production, it should be clear that high-quality genetics, for example, are most heavily influenced by price, quantity, and revenue changes in the Choice market. So, to the extent that we observe larger changes in revenue for the Choice market, the return to factors of production used to produce Choice beef should experience larger revenue (and perhaps welfare) changes.

Although we abstract away from welfare, this paper offers several contributions to the literature. Although it is intuitive that a heterogeneous model generates different results than a homogeneous quality model, it is not entirely clear how results will be different. A homogeneous quality model is silent regarding the effect of exogenous shocks on changes in quality and price premiums. This paper provides insight into the direction and magnitude of quality and price premiums that might be expected after a supply and demand shock.

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