Ethanol and Meat: A Multi-Market Analysis

Suparna Bhattacharya
PhD Candidate
University of Nebraska-Lincoln

Azzeddine M. Azzam
Professor
University of Nebraska-Lincoln

Darrell Mark
Associate Professor
University of Nebraska-Lincoln

Contact Author:

Suparna Bhattacharya
314E Filley Hall
Department of Agricultural Economics
University of Nebraska-Lincoln

E-mail: suparna.bhattacharya@huskers.unl.edu

Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2009 AAEA & ACCI Joint Annual Meeting, Milwaukee, WI, July 26-28, 2009.

Ethanol and Meat in the U.S.: A Multi-Market Analysis

Abstract

Since corn is the primary feedstock used for producing ethanol in the U.S., and ethanol production yields byproducts that can be fed to livestock in combination with corn, addressing the effect of ethanol production on meat markets should consider not only demand and supply interdependence between corn, ethanol, and ethanol byproducts; but also demand and supply interdependence between different types of meats. This paper develops a multi-market equilibrium displacement model to account for the interdependence. Six markets are considered: beef, pork, poultry, corn, ethanol, and ethanol byproducts. Results show that poultry is the most sensitive to ethanol production, followed by beef and pork.

1. Introduction

Since 1978, the U.S. government has been subsidizing biofuels as part of a policy response to the oil crisis during 1970s. The ethanol subsidy ranges between $1.05 and $1.38 per gallon of ethanol or between $1.42 and $1.87 per gallon of gasoline equivalent (Koplow, 2006). The main goal of the subsidy varied over time (Tyner, 2007). Initially it was given to support corn prices and farm incomes. With the Clean Air Act of 1990, gasoline was required to have a certain percentage of oxygen for environmental benefits. The result was a boost in demand for ethanol and petroleum-based oxygenate methyl tertiary butyl ether (MTBE). However, realizing in 2000 that MTBE causes environmental problems due to its toxicity and water contamination, 20 states banned MTBE in 2005, thus opening up the market for ethanol.

More recently, as energy security and global warming became major concerns, biofuels are considered not only as an alternative domestic fuel source to decrease the dependency on oil imports, but also as an important source to reduce greenhouse gas emission. In 2005, the Energy Policy Act mandated that renewable fuel use in gasoline reach 7.5 billion by 2012. Under the renewable fuels standard, a small percentage of fuel supply in the U.S. should be provided by renewable domestic fuels.

Federal tax laws provide incentives to the blenders for adding each gallon of ethanol with gasoline. Tax credits equal to 51 cents for each gallon of ethanol blended with gasoline are available to blenders. These tax credits indirectly subsidize ethanol producers in the form of benefits that are passed from blenders to producers.

Since the primary feedstock used for producing ethanol in the U.S. is corn and about half of the corn crop is fed to livestock in the U.S., developments in the ethanol

market impact the U.S. livestock sector through the corn market. However, production of ethanol also yields distilled dry grains (DGs) which can be used in combination with corn to feed livestock and poultry.[1] This suggests that increased availability of DGs may mitigate the effect of high corn prices on livestock feeders and meat consumers. The question is by how much, if at all.

Of the dozens of ethanol studies that recently appeared in economics journals,[2] only Tokgoz et al. (2008) have touched on the question as part of a larger study of the impact of ethanol on agricultural sectors. Using an econometric biofuels model in combination with an econometric multimarket model of world agriculture and food markets, the authors considered two scenarios. One involves a $10 rise in the price of crude oil. The other involves a 1988-type drought. In both cases, meat prices rose, with beef experiencing the largest increase (2.1%-3.9%), followed by broilers (2%-2.8%) and pork (1.5%-2.1%).

In this paper we address the byproducts question using a multi-market equilibrium displacement model (EDM). The advantage of EDM is that it is less data intensive; requiring only existing demand and supply estimates; and can be replicated easily and expanded by other researchers. Elaborate econometric models, like those used by Tokgoz et al., while useful, reside in specialized research centers, are data intensive, and usually not readily accessible for independent use by researchers outside the centers.

[1] Research suggests that DGs can make up 30-40% of feed cattle rations and up to 10-20% for hogs and poultry (Anderson, et al., 2008).
[2] Representative examples of the studies can be found in two special issues of *Journal of Agricultural and Food Industrial Organization* (JAFIO, 2007 and JAFIO, 2009).

Specifically, multi-market equilibrium displacement model we propose considers six markets – beef, pork, chicken, corn, ethanol, and ethanol byproducts, and their interrelatedness. The next section gives a brief and general description of EDM. Section 3 presents the graphical and algebraic structure of the multi-market model without displacement. Section 4 describes the multi-market in its EDM form. Section 5 presents the numerical EDM solution. Section 6 focuses on the livestock and poultry price and quantity effect of changes in corn and byproduct prices. Summary and conclusion are in the final section.

2. EDM: a general description

The equilibrium displacement model, also known as the "Muth model", is a widely used tool for agricultural price and policy analysis. First developed by Muth (1964), the original purpose of the model was to derive the elasticity of factor demand and supply functions of an industry using a simple one commodity-two input model.

In EDM, a particular market is first characterized by a set of supply and demand functions without assuming any particular functional form. Total differentiation of supply and demand equations is performed and changes in both endogenous and exogenous variables are expressed in proportionate terms or as ratios of proportionate changes i.e. (elasticities). The result is a new set of equations that, when solved simultaneously, approximate changes from the initial equilibrium induced by a shock or disturbance in the model.

Though EDM involves comparative statics, it does differ from the latter (Piggott 1992). Usually comparative statics involves the use of calculus to determine the direction of change in endogenous variables due to a change in an exogenous variable.

EDM is a distinctive form of comparative statics where more attention is given to finite changes in exogenous variables and changes in both endogenous and exogenous variables are measured in proportionate terms or as ratios of proportionate changes (elasticities). Thus the main advantages of the framework is that It allows qualitative and quantitative assessment of the effects on endogenous variables due to infinitesimal changes in exogenous variables; and can be used as a substitute to econometric modeling which, as we indicated earlier, is quite data intensive especially for multimarket analysis. More conveniently, the effects can be measured by using elasticity estimates from previous econometric studies, constraints from economic theory, intuition, or all three (Piggott, 1992).

3. Characterization of the multi-market structural model

3.1 Graphical characterization

As mentioned earlier, six markets are considered: beef, pork, poultry, corn, ethanol, and ethanol byproducts. Each market is characterized by a series of primary and derived demand and supply relationships. The relationships are illustrated graphically in figure 1.

To simplify the figure, panels A, B, and C represent the vertical linkage between retail, wholesale and farm for all the three meats together. The three meats will be considered separately in the algebraic model. Retail demand (D_R) in panel A and farm supply (S_F) in panel C are the “primary” relations. Demand facing wholesalers (DD_W) in panel B, and demand facing farmers (DD_F) in panel C, wholesale supply (DS_W) in panel B, and retail supply (DS_R) in panel A are the “derived” relations (Tomek and Robinson, 1990). Intersection of demand and supply at each level of the vertical chain determines

the market-clearing price and quantity. For simplicity, we assume fixed input proportions and a perfectly elastic supply curve of marketing inputs. With fixed input proportions, the elasticity of substitution between meat and marketing inputs is zero. Perfectly elastic supply of marketing inputs means that a change in the quantity of marketing inputs leaves retail-wholesale-farm margin unchanged. This allows drawing the derived demand schedule at wholesale parallel to the primary demand schedule, and the derived demand schedule at the farm parallel to the derived demand schedule at wholesale.

With these assumptions, the derived demand at wholesale is obtained as retail demand less the retail-wholesale margin (M) at each quantity level i.e. $DD_W = (D_R - M)$. The farm derived demand is wholesale derived demand less the wholesale-farm marketing margin (M') at each quantity level, i.e., $DD_F = (DD_W - M')$. The marketing margin M represents marketing cost which is the difference between retail and wholesale price. Marketing costs include packaging, retailing, etc. Margin M' is the difference between wholesale and farm price and costs include slaughtering, cleaning, etc. Similarly, derived supply at wholesale (retail) is obtained by adding an appropriate margin M' (M) to the primary supply (wholesale derived supply) function. To further simplify graphical illustration, we assume a one-to-one relationship between the outputs at the different links of the marketing chain. The assumption is dropped in the algebraic model.

Panels D, E, and F represent the respective derived demands for corn by the livestock, poultry, and ethanol industries. Panel G is the horizontal summation of those demands. Below panel F is panel J which shows the amount of byproduct produced as

a result of converting corn to ethanol. The conversion factor is represented by the upward sloping schedule emanating from the origin in panel J. Panel H and I show the respective demands for byproducts by cattle feeders and hog feeders. Panel K represents the ethanol market. All solid lines in the panels are associated with the initial equilibrium. The initial equilibrium prices and quantities in the different markets are as follows: P_E and Q_E in the ethanol market, P_R and Q_R in the ethanol-byproducts market (with byproduct quantity Q_{RP} is utilized by hog feeders and byproduct quantity Q_{RB} by cattle feeders). In panel G, total corn utilization Q_C is the sum of corn utilization in livestock (cattle and hogs) Q_{CL}, in poultry Q_{CK}, and ethanol Q_{CE}. Equilibrium quantity in the meat market is given by Q_M. Equilibrium prices are P_R at retail, P_W at wholesale, and P_F at the farm.

Suppose demand in the ethanol market (panel K) shifts from D_E to D_E'. Ethanol quantity increases from Q_E to Q_E', and ethanol price rises from P_E to P_E'. With a rise in the price of ethanol, derived demand for corn by ethanol plants shifts from DD_E to DD_E' increasing utilization from Q_{CE} to Q_{CE}'. Consequently, total corn demand (D_C) shifts rightwards, resulting in a rise in the price of corn from P_C to P_C', and an increase in quantity from Q_C to Q_C'. Assuming for now derived demand for corn by livestock and poultry does not shift, higher corn price reduce quantities fed to livestock and poultry. Their respective utilizations of corn are indicated by Q_{CL}' (panel D) and Q_{CK}' (panel E). Whether the derived demand for corn by livestock and poultry feeder shifts to the left, to the right, or stays the same, depends whether the output effect is smaller, larger, or equal to the substitution effect.

The effect of the shift in ethanol demand shock on the supply and demand of byproducts is shown by panels H, I, and J, respectively. Supply of ethanol byproducts shifts from Q_R to Q_R'. Given the total derived demand for ethanol-byproduct (D_R), which is the horizontal summation of the derived demands by cattle feeders (DD_B) in panel H and hog producers (DD_P) in panel I, the price of ethanol byproducts drops from P_R to P_R' .

The initial market farm supply in the meat market is determined by the intersection of the farm supply curve S_F and the derived demand curve DD_F. Quantity produced at farm is Q_M and price is P_F. At wholesale, derived demand DD_W intersects derived supply DS_W and equilibrium price (P_W) and quantity (Q_M). At retail, price P_R is determined where primary demand D_R and derived supply DS_R intersects at quantity Q_M.

Assuming that the price increase in corn more than offsets the decrease in ethanol byproduct price, farm supply shifts upward/leftward in beef, pork, and poultry markets. The shift translates into additional costs to suppliers downstream. Assuming no shift in consumer demand, increased costs are reflected by an upward shift in the derived wholesale and retail supply curve. The size of these shifts depends on the relative supply elasticities and own demand elasticities. Prices will rise and quantities will decline throughout the vertical chain. Price increases are indicated by P_R' at retail, P_W' at wholesale, and P_F' at the farm. Meat output declines from Q_M to Q_M'. When the three meats are considered separately, as is case in the next section, cross price elasticities will also be important determinants of the direction as well as the magnitude of changes in prices and quantities in all markets.

3.2 Algebraic characterization

The algebraic structural model is guided by the structure of the graphical model presented in the previous section. The model consists of 28 equations and is presented in Appendix 1. Definitions of model variables are in Appendix 2.

Equations **A-1.1** and **A-1.2** represent primary retail demand and derived retail supply of beef, respectively. Retail demand is a function of the retail beef price (PRB) and retail prices of the two major substitutes: pork and chicken (PRK, PRP). Retail supply is derived implicitly from the condition of profit maximization of a competitive firm, Price = marginal cost (MC), where MC is a function of input price upstream. Marginal cost of retail beef is a function of price of beef at wholesale.

Equations. **A-1.3** and **A-1.4** are the derived demand for beef by retailers and derived supply of beef by processors at wholesale. Following Diewert (1971), derived demand is obtained by Shephard's Lemma from the unit cost function c(PWB, PRM), where PWB and PRM are the prices of wholesale beef and marketing inputs, respectively. The unit cost function represents the minimum cost of producing one unit of output given PWB and PRM. Supply of marketing inputs is assumed to be perfectly elastic. The amount of cost minimizing input required to produce choice beef QRB is given by A-1.3 (QWB = cwb. QRB). By Shephard's Lemma, cwb is the partial derivative of unit cost function c (PWB, PRM) with respect to input price PWB. The variable QRB is retail beef output. The derived supply of beef at wholesale (A-1.4) is implicit in the profit maximizing condition Price = MC. Here, marginal cost is a function of the price of fed cattle at the farm (PFB).

Equations **A-1.5** and **A-1.6** are the derived demand and primary supply of fed cattle. The derived demand for fed cattle (QFB) is found using the unit cost function c (PFB, PWM) required to produce a given output of wholesale beef (QWB), where QFB is the cost minimizing amount of fed cattle needed to produce QWB. The primary supply of fed cattle is a function of own price of fed cattle (PFB), the price of corn (PC), and the price of ethanol byproducts (PR).

Equations **A-2.1** to **A-2.6** represent the pork market supply and demand functions at retail, wholesale, and farm level. Interpretation and theoretical justification of the pork equations are similar to those in the beef market.

Equations **A-3.1** to **A-3.4** capture primary and derived demand, and supply functions in the poultry market at retail and wholesale level. Retail demand and supply are derived in the similar way as mentioned above for the beef and pork sectors. However, unlike beef and pork, there is no farm price in the poultry market. Virtually all broilers are produced under contracts where the integrator (the poultry slaughter company) supplies chicks and feed and pays growers a per-unit fee for the birds they produce. Thus, the supply function at wholesale considers marginal cost of processors as a function of the price of the corn.

Equations **B-1** through **B-4** represent derived demand for corn by the livestock, poultry, and ethanol markets, respectively. The equations are derived using the unit cost function c (PC, PR), where PR is the corn price and PR is the byproducts price. Equation **B-5** is total derived demand for corn. The total consists of the derived demand for corn in the cattle, hog, poultry, ethanol, and export markets. Exports are taken as given. Equation **B-6** is the market supply of corn.

Equations **C-1** and **C-2** are ethanol demand and supply functions. Demand is a function of the ethanol price and a demand shifter. Ethanol supply is a function of the corn price and other inputs prices (PG) used to produce ethanol.

Equations **C-3** and **C-4** are the derived demand functions for byproducts by cattle and hog feeders. The equations are derived using the unit cost function where price of corn and price of byproducts are considered the input prices. Since market supply of both corn and byproduct are assumed less than perfectly elastic, changes in both these input prices are important in determining the changes in derived demand for ethanol byproducts when a shock is introduced in the ethanol market.

Equations **C-5** and **C-6** represent the total market demand and supply of byproducts. Demand is the horizontal summation of derived demand by cattle feeders and hog producers. Because the use of byproducts in chicken industry is negligible, it is not considered in the model. Byproduct supply is assumed to be a fixed proportion of the quantity of corn consumed by ethanol plants. Research shows that five billion gallons of ethanol uses 2 billion bushels (50 million tons) of corn and generates approximately 7.5 million tons of corn glutten feed and 6.5 million tons of DDG (Ferris and Joshi, 2005).

4. Equilibrium Displacement Model

The equilibrium displacement model, shown in Appendix 3, is obtained by totally differentiating equations (A-1.1) through (C-6) in Appendix 1 and expressing the result in percentage terms. Definitions of EDM variables and parameters are in Appendix 4.

For a given set of elasticity estimates Eqs. (*a-1.1*) through (*c-6*) are used to determine the relative changes in quantities and prices induced by an exogenous

change in ethanol demand. The model contains of 28 endogenous variables. The exogenous variables in the model are δ, pg, and ddcx. However, to focus on the effect of a change emanating from the ethanol market, as represented by *δ,* we set the change in the exogenous variables pg and ddcx to zero.

To solve for the changes in the 28 endogenous variables, Eqs. (*a-1.1*) through (*c-6*) are written in the matrix form

$$A \cdot X = B, \qquad (3.1)$$

where A is a 28x28 matrix that consists of the parameters defining the inter-relationship between endogenous variables, X is a 28x1 vector of (unknown) changes in the endogenous prices and quantity variables, and B is a 28x1 vector of exogenous variables.

Using the estimates in Appendix 5 for the elements in the A matrix, and assigning a specific percentage change to *δ,* the solution to X is given by

$$X = A^{-1}B \qquad (3.2)$$

5. Results

Setting *δ* to 10%, the proportionate changes in all the endogenous variables were found using Excel. The changes are in Appendix 6.

Results indicate that a 10% increase in ethanol demand leads to 7% rise in the quantity of ethanol and 2.7% rise in its price. The price rise induces a 5.7% rise in the corn utilization. This rise in corn demand in the ethanol market shifts total demand for corn rightwards, leading to a 4.5% rise in the price of corn and a 1.03% increase in the quantity of corn. The higher corn price results in less corn consumption. The decline is 4.05% in the cattle sector, 2.38% in the pork sector, and 8.55% in the poultry sector.

As mentioned earlier, the supply of byproducts is tied to the amount of corn used to ethanol plants. With the increase corn demand by ethanol plants, supply of ethanol byproducts also increases. Specifically, byproduct quantity increases by 5.7% and its price declines by 4%. With increased availability of this alternative feedstock at a lower price, its demand in livestock sector rises. Quantity demanded in the cattle sector increases by 9.5% and in the hog sector by 3.11%.

Since the amount of corn used for feeding beef and pork is higher than the amount of byproduct, as represented by the cost share of corn in Appendix 5, the rise in the corn price increases the cost of feeding. Here feed cost is considered a major component of the cost of production. Cattle and hog supply shifts inwards leading to a decline in quantity and a rise in price. In the beef market, quantities decline by 0.34%, 0.29%, and 0.21%, whereas prices rise by 0.33%, 0.26%, and 0.14% at farm, wholesale, and retail segments, respectively. In the pork market, quantities decline by 0.18%, 0.12%, and 0.05%, while prices go up by 0.52%, 0.35%, and 0.15% at farm, wholesale, and retail segments.

The impact of ethanol expansion in the poultry market is quite sizable. The rise in corn price increases the cost of production of processors at wholesale. The supply curve shifts upwards/leftwards and quantities fall with rise in prices at both wholesale and retail. Quantities of poultry decrease by 1.07% and 0.85% whereas prices increase by 3.14% and 1.1% at wholesale and retail sectors.

6. Price and quantity effect of changes in the prices of ethanol, corn, and byproducts

From the EDM solution we can derive own- and cross elasticities of interest by simply dividing the percentage changes in quantities by the pertinent percentage changes in prices. Since our focus is the effect of ethanol market on meat markets via its effect on corn and byproduct markets, we provide the price and quantity effects in each market of a change in the price of ethanol (Appendix 7), the price of corn (appendix 8), and the price of byproducts (Appendix 9). All elasticities are total, not partial. In other words, they take into account displacement in all six markets following a 10 percent rise in ethanol demand.

Appendix 7 focuses on the responses of prices and quantities in the meat marketing channel to a change in the price of ethanol. Rows 1-3 in appendix show the respective ethanol-price elasticities of demand for beef, pork, and poultry at retail, rows 4-6 at wholesale, and rows 7 and 8 at the farm. All elasticities are less than 1, suggesting inelastic response throughout the vertical chain for all three meats. Chicken demand is the most the sensitive, especially at the wholesale level, followed by beef and pork. The sensitivity of prices of the individual meats to a rise in the price of ethanol mirrors the sensitivity of quantities but in the opposite direction. Chicken shows the largest percentage price increase, followed by pork and beef.

Appendix 8 focuses on the responses of prices and quantities in the meat marketing channel to a change in corn prices. Mirroring results in Appendix 7, all elasticities are in the inelastic range with chicken demand being most elastic, especially at the wholesale level, followed by beef and pork. The sensitivity of prices of the

individual meats to a rise in the price of corn mirrors the sensitivity of quantities but in the opposite direction. Chicken shows the largest percentage price increase, followed by pork and beef.

Appendix 9 summarizes responses of prices and quantities in the meat marketing channel to a change in price of ethanol-byproducts. The effect on prices and quantities this time is opposite that of the effect of corn. Quantities rise and prices decline. This is to be expected since the price of corn and the price of byproducts go in the opposite direction following the demand shift in ethanol. A rise in byproduct prices implies a decline in corn prices since less corn is being utilized by ethanol plants. Since the decline in the corn price more than offset the rise in the byproduct price, meat quantities rise and meat prices decline.

7. Conclusion

Since corn is the primary feedstock used for producing ethanol in the U.S., and production of ethanol also comes with a range of byproducts that can be fed to livestock in combination with corn, addressing the effect of ethanol production on meat markets should consider the interrelatedness between the corn market and ethanol co-product market.

In this paper we study the linkage between the ethanol and the meat market by using a multi-market equilibrium displacement model (EDM) that considers six markets – beef, pork, chicken, corn, ethanol, and ethanol byproducts, and their interrelatedness. What we find is that a 10% percent shift in ethanol demand raises the corn price by 4.48%. This leads to a decline in corn demand by 4.05% for cattle, 2.38% for hogs, and 8.55% for chicken. The quantity supplied of byproducts rises by 5.7% and its price

declines 3.96%. The price decline leads to 9.5% increase byproduct utilization in cattle sector and 3.11% in the hog sector.

We also provide total elasticities of prices and quantities in the meat marketing channel with respect to changes in the price of ethanol, the price of corn, and the price ethanol by products. In all cases the most sensitive sector is the poultry sector, followed by beef and pork.

REFERENCES

Anderson, D., J.D. Anderson, and J. Sawyer. "Impact of Ethanol Boom on Livestock and Dairy industries: What Are They Going to Eat?" *Journal of Agricultural and Applied Economics* 40(2008):573-579.

Diewert, W. E. "A note on the Elasticity of Derived Demand in the N- Factor Case." *Economica.* 38(1971):192-198.

Ferris, J. N., and S.V. Joshi (2005) An Econometric Analysis of the Impact of the Expansion in the U.S. Production of Ethanol from Maize and Biodiesel from soybeans on Major Agricultural Variables, ed. J. Outlaw, K. Collins, and J. Duffield, 'Agriculture as a Producer and Consumer of Energy'., CABI Publishing, 156-167.

Heien, D. "An Economic Analysis of the U.S. Poultry Sector." *The Review of Economics and Statistics.* 57(1975):370-375.

Heien, D. "An Econometric Model of the U.S. Pork Economy." *American Journal of Agricultural Economics.* 58(1976):311-316.

Hill, J., *et al*. "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels." Proceedings of the National Academy of Sciences, 2006.

Journal of Agricultural and Food Industrial Organization. "Explorations in Biofuels Economics, Policy, and History." Special Issue 5(2007)

Journal of Agricultural and Food Industrial Organization. "Special Issue in Memory of Bruce Gardner 1942-2008: Contributions to Energy Economics and Policy Analysis." Special Issue 6(2008).

Koplow, D. "Biofuels – At What Cost?" Government Support for Ethanol and Biodiesel in the United States. Geneva, Switzerland, Global Subsidies Initiative of the International Institute for Sustainable Development, 2006.

Lusk, J. L., and F. B. Norwood. "Modeling Beef Quality Heterogeneity." *Journal of Agricultural and Applied Economics.* 37(2005):603-618.

Marsh, J. M. "Estimating Intertemporal Supply Response in the Fed Beef market." *American Journal of Agricultural Economics.* 76(1994):444-453.

Miranowski, John A. "Biofuel Incentives and the Energy Title of the 2007 Farm Bill," American Enterprise Institute.

http://www.aei.org/docLib/20070515_miranowskifinal.pdf

Muth, R. F. “The Derived Demand Curve for a Productive Factor and the Industry Supply Curve.” *Oxford Economic Papers.* 16(1964):221-234.

Piggott, R. R. “Some Old Truths Revisited.” *Australian Journal of Agricultural Economics.* 36(1992):117-140.

Schmidhuber, J. “Impact of an Increased Biomass Use on Agricultural Markets, Prices, and Food Security: A Longer-Term Perspective.” Paper prepared for the International Symposium of Notre Europe, Paris, 2006.

Shapouri, H., and P. Gallagher. “USDA’s 2002 Ethanol Cost-of-Production Survey.” USDA, 2002.

Sechhi, S., and B.A. Babcock. “Impact of High Crop Prices on Environmental Quality: A Case of Iowa and the Conservation Reserve Program.” Working Paper 07-WP 447, Center for Agricultural and Rural Development, Ames, Iowa, 2007.

Stoddart, H. R. “The North American Hog and Pork Industry: Implications of a Countervailing Duty on Pork.” *American Journal of Agricultural Economics.* 73(1991):1562-1569.

Tomek, W. G., and K. L. Robinson. *Agricultural Product Prices* Chapter 6. Ithaca, N.Y.: Cornell University Press, 1990.

Tokgoz, S.,, A. Elobeid, J. Fabiosa, D. J. Hayes, B. A. Babcock, T Yu, F. Dong, and C. E. Hart. "Bottlenecks, Drought, and Oil Price Spikes: Impact on U.S. Ethanol and Agricultural Sectors.” *Review of Agricultural Economics* 30(2008):604-622.

Tyner, W. E. "Policy Alternatives for the Future Biofuels Industry." *Journal of Agricultural & Food Industrial Organization*. 5(2007).

Wohlgenant, M. K. “Demand for Farm Output in a complete System of Demand Functions.” *American Journal of Agricultural Economics.* 71(1989):241-252.

Wohlgenant, M. K. “Distribution of Gains from Research and Promotion in Multi-Stage Production Systems: The Case of the U.S. Beef and Pork Industries.” *American Journal of Agricultural Economics.* 75(1993):642-651.

Appendix 1. Multi-market structural model

A Livestock and Poultry Market

1) Beef Market

Retail demand for beef by consumers
A-1.1 QRB = QRB (PRB, PRK, PRP)

Retailer supply of beef
A-1.2 PRB = MCRB (PWB)

Derived demand for beef by retailers
A-1.3 QWB = cwb. QRB

Supply of beef by processors
A-1.4 PWB = MCWB (PFB)

Derived demand for fed cattle by processors
A-1.5 QFB = cfb. QWB (PWB)

Farm supply of fed cattle
A-1.6 QFB = QFB (PFB, PC, PR)

2) Pork Market

Retail demand for pork by consumers
A-2.1 QRP = QRP (PRB, PRK, PRP)

Retailer supply of pork
A-2.2 PRP = MCRP (PWP)

Derived demand for pork by retailers
A-2.3 QWP = cwp. QRP

Supply of pork by processors
A-2.4 PWP = MCWP (PFP)

Derived demand for pork by processors
A-2.5 QFP = cfp. QWP (PWP)

Farm supply of pork
A-2.6 QFP = QFP (PFP, PC, PR)

3) Poultry Market

Retail demand for chicken by consumers
A-3.1 QRK = QRK (PRB, PRK, PRP)

Retailer supply of chicken
A-3.2 PRK = MCRK (PWK)

Derived demand for chicken by retailers
A-3.3 QWK = cwk. QRK

Supply of chicken by processors
A-3.4 PWK = MCWK (PC)

B) Corn Market

Derived demand for corn by cattle feeders
B-1 DDCT = ctpc. QFB (PFB)

Derived demand for corn by hog producers
B-2 DDCP = cppc .QFP (PFP)

Derived demand for corn by chicken growers
B-3 DDCK = ckpc .QWK

Derived demand for corn by ethanol producers
B-4 DDCE = cepc .QWE (PWE)

Total derived demand for corn
B-5 QDC = DDCT + DDCP + DDCK + DDCE + DDCX

Market supply of corn
B-6 QSC = QSC (PC)

C) Ethanol and Byproduct Market

Ethanol demand
C-1 QWE = QWE (PWE, δ)

Ethanol supply
C-2 PWE = MCWE (PC, PG)

Derived demand for ethanol byproducts by cattle feeders
C-3 DDRT = ctpr. QFB (PFB)

Derived demand for ethanol byproducts by hog producers

C-4 DDRP = cppr. QFP (PFP)

Total derived demand for ethanol byproducts

C-5 QDR **=** DDRT + DDRP

Market supply of ethanol byproducts

C-6 QSR = λ. DDCE

Appendix 2. Definitions of Variables

Beef Structural Model

QRB	quantity of choice beef demanded at retail by consumers
PRB	price of beef at retail
PRK	price of chicken at retail
PRP	price of pork at retail
MCRB	marginal cost of retail beef
PWB	price of wholesale beef
QWB	quantity of wholesale beef demanded by retailers
cwb	derivative of unit cost function c(PWB, PRM) with respect to wholesale beef price
PRM	price of the marketing inputs at retail level
MCWB	marginal cost of beef at wholesale
PFB	price of fed cattle at farm level
QFB	quantity of fed cattle demanded by processors
cfb	derivative of unit cost function c(PFB, PWM) with respect to fed cattle price
PWM	price of the marketing inputs at wholesale level
PC	price of corn
PR	price of ethanol byproduct

Pork Structural Model

QRP	quantity of pork demanded at retail by consumers
MCRP	marginal cost of pork at retail
PWP	price of wholesale pork
QWP	quantity of pork demanded by retailers at wholesale

cwp	derivative of unit cost function c(PWP, PRM) with respect to wholesale pork price
MCWP	marginal cost of pork at wholesale
PFP	price of pork at farm level
QFP	quantity of pork demanded by processors at farm level
cfp	derivative of unit cost function c(PFP, PWM) with respect to price of pork

Poultry Structural Model

QRK	quantity of chicken demanded at retail by consumers
MCRK	marginal cost of chicken at retail
PWK	price of wholesale chicken
QWK	quantity of chicken demanded by retailers at wholesale
cwk	derivative of unit cost function c(PWK, PRM) with respect to wholesale chicken price
MCWK	marginal cost of chicken at wholesale

Corn Structural Model

DDCT	derived demand for corn by cattle feeders
ctpc	derivative of unit cost function c(PC, PR) of cattle feeders with respect to price of corn
DDCP	derived demand for corn by hog producers
cppc	derivative of unit cost function c(PC, PR) of hog producers with respect to price of corn
DDCK	derived demand for corn by chicken growers
ckpc	derivative of unit cost function c(PC, PM) of chicken growers with respect to price of corn
PM	price of other inputs used by chicken growers

DDCE derived demand for corn by ethanol plants

cepc derivative of unit cost function c(PC, PG) of ethanol producers with respect to price of corn

QWE quantity of ethanol demanded

PWE price of ethanol

QDC Total derived demand for corn

DDCX derived demand for corn by exporters

QSC total supply of corn

Ethanol and Byproduct Structural Models

δ demand shifter in ethanol market

MCWE marginal cost to produce ethanol

PG price of natural gas used for ethanol production

DDRT derived demand for ethanol byproducts by cattle feeders

ctpr derivative of unit cost function c(PC, PR) of cattle feeders with respect to price of ethanol byproduct

DDRP derived demand for ethanol byproducts by hog producers

cppr derivative of unit cost function c(PC, PR) of hog producers with respect to price of ethanol byproduct

QDR total derived demand for ethanol byproducts

QSR market supply of ethanol byproducts

λ proportion of ethanol production that is byproduct .

Appendix 3. Equilibrium Displacement Model

a) Livestock and Poultry Market

1) Beef Market

a-1.1 $qrb - \eta bb\ prb - \eta bk\ prk - \eta bp\ prp = 0$

a-1.2 $prb - swb\ pwb = 0$

a-1.3 $qwb + (1 - swb)\ \sigma wbm\ pwb - qrb = 0$

a-1.4 $pwb - sfb\ pfb = 0$

a-1.5 $qfb + (1 - sfb)\ \sigma fbm\ pfb - qwb = 0$

a-1.6 $qfb - \varepsilon bb\ pfb - \varepsilon bc\ pc - \varepsilon br\ pr = 0$

2) Pork Market

a-2.1 $qrp - \eta pb\ prb - \eta pk\ prk - \eta pp\ prp = 0$

a-2.2 $prp - swp\ pwp = 0$

a-2.3 $qwp + (1 - swp)\ \sigma wpm\ pwp - qrp = 0$

a-2.4 $pwp - sfp\ pfp = 0$

a-2.5 $qfp + (1 - sfp)\ \sigma fpm\ pfp - qwp = 0$

a-2.6 $qfp - \varepsilon pp\ pfp - \varepsilon pc\ pc - \varepsilon pr\ pr = 0$

3) Poultry Market

a-3.1 $qrk - \eta kb\ prb - \eta kk\ prk - \eta kp\ prp = 0$

a-3.2 $prk - swk\ pwk = 0$

a-3.3 $qwk + (1 - swk)\ \sigma wkm\ pwk - qrk = 0$

a-3.4 $pwk - sck\ pc = 0$

b) Corn Market

b-1 $ddct + (1 - sct)\ \sigma cr\ pc - (1 - sct)\ \sigma cr\ pr - qfb = 0$

b-2 $ddcp + (1 - scp)\ \sigma cr\ \ pc - (1 - scp)\ \sigma cr\ \ pr - qfp = 0$

b-3 $ddck + (1 - sck)\ \sigma cr\ \ pc - qwk = (1 - sck)\ \sigma cm\ \ pm$

b-4 $ddce + (1 - sce)\ \sigma cg\ \ pc - qwe = (1 - sce)\ \sigma cg\ \ pg$

b-5 $qdc - SCT\ \ ddct - SCP\ \ ddcp - SCK\ \ ddck - SCE\ \ ddce = SCX\ \ ddcx$

b-6 $qsc - \varepsilon cc\ \ pc = 0$

***c*)** **Ethanol and Byproduct Market**

c-1 $qwe - \eta ee\ \ pwe = - \eta ee\ \ \delta$

c-2 $pwe - sce\ \ pc = sge\ \ pg$

c-3 $ddrt - sct\ \ \sigma cr\ \ pc + sct\ \ \sigma cr\ \ pr - qfb = 0$

c-4 $ddrp - scp\ \ \sigma cr\ \ pc + scp\ \ \sigma c\ r\ pr - qfp = 0$

c-5 $qdr - SRT\ \ ddrt - SRP\ \ ddrp = 0$

c-6 $qsr - ddce = 0$

Appendix 4. Definitions of parameters and variables in Equilibrium Displacement Model

Beef

qrb the percent change in the retail demand for beef by consumers

prb the percent change in the price of beef at retail

prk the percent change in the price of chicken at retail

prp the percent change in the price of pork at retail

pwb the percent change in the price of wholesale beef

qwb the percent change in the derived demand for beef by retailers

pfb the percent change in the price of beef at farm level

qfb the percent change in the derived demand for fed cattle by processors

pc the percent change in the price of corn

pr the percent change in the price of ethanol byproducts

Pork

qrp the percent change in the retail demand for pork by consumers

pwp the percent change in the price of wholesale pork

qwp the percent change in the derived demand for pork by retailers

pfp the percent change in the price of pork at farm level

qfp the percent change in the derived demand for pork by processors

Poultry

qrk the percent change in the retail demand for chicken by consumers

pwk the percent change in the price of wholesale chicken

qwk the percent change in the derived demand for chicken by retailers

Corn

ddct the percent change in derived demand for corn by cattle feeders

ddcp the percent change in derived demand for corn by hog producers

ddck the percent change in derived demand for corn by chicken growers

ddce the percent change in derived demand for corn by ethanol plants

qwe the percent change in the ethanol demand

qdc the percent change in the total derived demand for corn

ddcx the percent change in derived demand for corn by exporters

qsc the percent change in corn supply

Ethanol and Ethanol Byproduct

pwe the percent change in the price of ethanol

ddrt the percent change in derived demand for ethanol byproducts by cattle feeders

ddrp the percent change in derived demand for ethanol byproducts by hog producers

qdr the percent change in derived demand for ethanol byproducts

qsr the percent change in the supply of ethanol byproducts

3.5c Definitions of Parameters in Equilibrium Displacement Model

Beef

ηbb own price elasticity of retail demand for beef

ηbk elasticity of retail demand for beef with respect to price of chicken

ηbp elasticity of retail demand for beef with respect to price of pork

swb cost share of beef for retailers defined as proportionate of total cost (PWB + PRM) spend on beef

σwbm elasticity of substitution between beef and marketing inputs used to produce retail beef

sfb cost share of beef for processors defined as proportionate of total cost (PFB + PWM) spend on beef

σfbm elasticity of substitution between beef and marketing inputs used to produce wholesale beef

εbb own price elasticity of fed cattle supply

εbc elasticity of supply of fed cattle with respect to price of corn

εbr elasticity of supply of fed cattle with respect to price of ethanol byproducts

Pork

ηpb elasticity of retail demand for pork with respect to price of beef

ηpk elasticity of retail demand for pork with respect to price of chicken

ηpp own price elasticity of retail demand for pork

swp cost share of pork for retailers defined as proportionate of total cost (PWP + PRM) spend on pork

σwpm elasticity of substitution between pork and marketing inputs used to produce retail pork

sfp cost share of pork for processors defined as proportionate of total cost (PFP + PWM) spend on pork

σfpm elasticity of substitution between pork and marketing inputs used to produce wholesale pork

εpp own price elasticity of pork supply

εpc elasticity of supply of pork with respect to price of corn

εpr elasticity of supply of pork with respect to price of ethanol byproducts

Poultry

ηkb elasticity of retail demand for chicken with respect to price of beef

ηkk own price elasticity of retail demand for chicken

ηkp elasticity of retail demand for chicken with respect to price of pork

swk cost share of chicken for retailers defined as proportionate of total cost (PWK + PRM) spend on chicken

σwkm elasticity of substitution between chicken and marketing inputs used to produce retail chicken

sck cost share of corn for wholesalers defined as proportionate of total cost (PC + PWM) spend on corn

Corn

sct cost share of corn used by cattle feeders defined as proportionate of feed cost (PC + PR) spend on corn

σcr elasticity of substitution between corn and ethanol byproducts

scp cost share of corn used by hog producers defined as proportionate of feed cost (PC + PR) spend on corn

sck cost share of corn used by chicken growers defined as proportionate of feed cost (PC + PM) spend on corn

pm percent change in the price of other inputs used to grow chicken

σcm elasticity of substitution between corn and other inputs used to grow chicken

sce cost share of corn used by ethanol plants defined as proportionate of feed cost (PC + PG) spend on corn

σcg elasticity of substitution between corn and energy

pg the percent change in the price of natural gas

SCT share of total corn output used by cattle feeders

SCP share of total corn output used by hog producers

SCK share of total corn output used by chicken growers

SCE share of total corn output used by ethanol plants

SCX share of total corn output exported

εcc own price supply elasticity of corn

Ethanol and Ethanol Byproduct

ηee own price elasticity of demand for ethanol

δ demand shifter in ethanol market

sge cost share of natural gas used by ethanol plants

SRT share of ethanol by-products output used by cattle feeders

SRP share of ethanol by-products output used by hog producers

Appendix 5. Parameter Estimates and their Sources

ηbb (own price elasticity of retail demand for beef)	-1.09	USDA (2007)
ηbk (elasticity of retail demand for beef with respect to price of chicken)	-0.06	USDA (2007)
ηbp (elasticity of retail demand for beef with respect to price of pork)	0.08	USDA (2007)
ηpp (own price elasticity of retail demand for pork)	-0.83	USDA (2007)
ηpb (elasticity of retail demand for pork with respect to price of beef)	0.1	USDA (2007)
ηpk (elasticity of retail demand for pork with respect to price of chicken)	0.05	USDA (2007)
ηkk (own price elasticity of retail demand for chicken)	-0.84	USDA (2007)
ηkb (elasticity of retail demand for chicken with respect to price of beef)	0.24	USDA (2007)
ηkp (elasticity of retail demand for chicken with respect to price of pork)	0.25	USDA (2007)
swb (cost share of beef for retailers)	0.55	USDA (2002); Lusk and Norwood (2005)
σwbm (elasticity of substitution between beef and marketing inputs used to produce retail beef)	0.70	Lusk and Norwood (2005)
sfb (cost share of beef for processors)	0.80	Lusk and Norwood (2005)

σfbm (elasticity of substitution between beef and marketing inputs used to produce wholesale beef)	0.70	Lusk and Norwood (2005)
ebb (own price elasticity of fed cattle supply)	0.15	Wohlgenant (1993)
ebc (elasticity of supply of fed cattle with respect to price of corn)	0.744	Marsh (1994)
epc (elasticity of supply of pork with respect to price of corn)	-0.095 -0.092 (SR) -0.742 (LR)	D. Heien (1975) H. Stoddart (1991)
ekc (elasticity of supply of chicken with respect to price of corn)	-0.02	Dale Heien (1976)
sct (cost share of corn used by cattle feeders)	0.65	D. Mark, Cattle budget for NE
σcr (elasticity of substitution between corn and ethanol byproducts)	0.65	Assumed
scp (cost share of corn used by hog producers)	0.6	Assumed
sck (cost share of corn used by chicken growers)	0.7	Assumed
sce (cost share of corn used by ethanol plants)	0.60	Shapouri and Gallagher (2002)
ecc (own price supply elasticity of corn)	0.23	USDA (2007)
srp (cost share of ethanol co-products used by hog producers)	0.02	http://porkcentral.unl.edu/, UNL

srt (cost share of ethanol co-products used by cattle feeders)	0.06	D. Mark, Cattle budget for Nebraska
ηee (own price elasticity of demand for ethanol)	-0.89	Miranowski (2007)
sge (cost share of natural gas used by ethanol plants)	0.14	Shapouri and Gallagher (2002)
swk (cost share of chicken for retailers)	0.35	USDA (2007)
σwkm (elasticity of substitution between chicken and marketing inputs used to produce retail chicken)	0.11	Wohlgenant (1989)
sfp (cost share of pork for processors)	0.67	USDA (2007)
σfpm (elasticity of substitution between pork and marketing inputs used to produce wholesale pork)	0.35	Wohlgenant (1993)
ebr (elasticity of supply of beef with respect to byproduct prices)	-0.74	Assumed
epr (elasticity of supply of pork with respect to byproduct prices)	-0.74	Assumed
epp (own price elasticity of pork supply)	0.40	Wohlgenant (1993)
swp (cost share of pork for retailers)	0.43	USDA (2007)
σwpm (elasticity of substitution between pork and marketing inputs used to produce retail pork)	0.35	Wohlgenant (1993)
SCT (share of total corn produced that is used by cattle feeders)	0.23	Nebraska Corn Board

SCP (share of total corn produced that is used by hog producers)	0.15	Nebraska Corn Board
SCK (share of total corn produced that is used by chicken growers)	0.2	Nebraska Corn Board
SCE (share of total corn produced that is used by ethanol plants)	0.38	Nebraska Corn Board
SRT (share of total byproduct produced that is used by cattle feeders)	0.5	Assumed
SRP (share of total byproduct produced that is used by hog producers)	0.3	Assumed

Appendix 6. Percent Changes in Endogenous Variables induced by a 10% increase in Ethanol Demand

1. Ethanol Market	
Quantity	6.6%
Price	2.7%
2. Ethanol Byproduct Market	
Quantity	5.7%
Price	-3.96%
Derived demand for byproduct by cattle feeders	9.5%
Derived demand for byproduct by hog producers	3.11%
3. Corn Market	
Quantity	1.03%
Price	4.48%
Derived demand for corn by cattle feeders	-4.05%
Derived demand for corn by hog producers	-2.38%
Derived demand for corn by chicken growers	-8.55%
Derived demand for corn by ethanol plants	5.7%
4. Beef Market	
Retail Sector	
Quantity	-0.21%
Price	0.14%
Wholesale Sector	
Quantity	-0.29%

Price	0.26%
Farm sector	
Quantity	-0.34%
Price	0.33%
5. Pork Market	
Retail Sector	
Quantity	-0.05%
Price	0.15%
Wholesale Sector	
Quantity	-0.12%
Price	0.35%
Farm Sector	
Quantity	-0.18%
Price	0.52%
6. Poultry Market	
Retail Sector	
Quantity	-0.85%
Price	1.1%
Wholesale Sector	
Quantity	-1.07%
Price	3.14%

Appendix 7. Elasticities of price and quantities in the beef, pork, and poultry sectors with respect to the price of ethanol

1	Quantity of retail beef	-0.077
2	Quantity of retail pork	-0.018
3	Quantity of retail chicken	-0.314
4	Quantity of wholesale beef	-0.107
5	Quantity of wholesale pork	-0.044
6	Quantity of wholesale chicken	-0.396
7	Quantity of Fed cattle	-0.126
8	Quantity of market hogs	-0.067
9	Price of retail beef	0.052
10	Price of retail pork	0.056
11	Price of retail chicken	0.407
12	Price of wholesale beef	0.096
13	Price of wholesale pork	0.123
14	Price of wholesale chicken	1.163
15	Price of fed cattle	0.122
16	Price of market hogs	0.193

Appendix 8. Elasticities of price and quantities in the beef, pork, and poultry sectors with respect to the price of corn

1	Quantity of retail beef	-0.047
2	Quantity of retail pork	-0.012
3	Quantity of retail chicken	-0.189
4	Quantity of wholesale beef	-0.065
5	Quantity of wholesale pork	-0.027
6	Quantity of wholesale chicken	-0.239
7	Quantity of Fed cattle	-0.075
8	Quantity of market hogs	-0.040
9	Price of retail beef	0.032
10	Price of retail pork	0.033
11	Price of retail chicken	0.245
12	Price of wholesale beef	0.058
13	Price of wholesale pork	0.077
14	Price of wholesale chicken	0.7
15	Price of fed cattle	0.073
16	Price of market hogs	0.115

Appendix 9. Elasticities of price and quantities in the beef, pork, and poultry sectors with respect to the price of ethanol byproducts

1	Quantity of retail beef	0.053
2	Quantity of retail pork	0.014
3	Quantity of retail chicken	0.215
4	Quantity of wholesale beef	0.074
5	Quantity of wholesale pork	0.031
6	Quantity of wholesale chicken	0.271
7	Quantity of Fed cattle	0.086
8	Quantity of market hogs	0.046
9	Price of retail beef	-0.036
10	Price of retail pork	-0.037
11	Price of retail chicken	-0.277
12	Price of wholesale beef	-0.066
13	Price of wholesale pork	-0.087
14	Price of wholesale chicken	-0.79
15	Price of fed cattle	-0.083
16	Price of market hogs	-0.130

Figure 1. Graphical representation of the multi-market displacement mode