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Economic Impacts of Zilmax® Adoption in Cattle Feeding

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The Food and Drug Administration recently approved the feeding of Zilmax® for cattle in the United States. This study determines direct net return benefits for early-adopting cattle feeders and beef packers. In addition, longer-run producer and consumer surplus measures are estimated as adoption impacts market prices and quantities. After markets adjust, cow-calf producers, cattle feeders, and consumers will gain from adopting the new technology.

Key words: cattle production technology; economic impacts of adoption; Zilmax®

Introduction

Agricultural production technology can have substantial impacts on multiple sectors of the food production, processing, and marketing chain. Direct economic impacts of adopting a new technology are estimates made when a firm decides whether or not to adopt. However, determining overall longer-term market impacts of adoption is necessary for understanding the technology's broader viability. Some technologies increase production efficiency, but face producer, processor, or consumer resistance because of a variety of potential concerns about the technology. Prime examples include genetically modified organism (GMO) crop production, use of recombinant bovine somatotropin (rBST) in the dairy industry, and cloning in the livestock industry (Brooks and Lusk, 2010; Foltz and Chang, 2002; Kanter, Messer, and Kaiser, 2009; Lusk, Roosen, and Fox, 2003). Like these examples, a recently approved technology in the beef industry, feeding zilpaterol hydrochloride (hereafter referred to by its brand name Zilmax®) to finishing cattle (Delmore, Hodgen, and Johnson, 2010), allows for an interesting assessment of potential economic impact because its adoption has been met with some resistance.

Despite the substantial economic benefits realized by producers that have adopted Zilmax® feeding, some producers and processors have taken public stands against the practice. Potential impacts on beef quality have caused some producers to opt not to feed Zilmax® and some packers to refuse cattle known to be fed the product (Richey, 2008; Yates, 2010). The objective of this study is to determine the economic impacts of Zilmax® adoption in the cattle and beef industry.

Quantifying economic impacts of Zilmax® is important for several reasons. First, it is necessary to understand how potential direct impacts on firms adopting the technology drive adoption outcomes. Producers and slaughterers especially need information on expected returns to help them make adoption decisions. This study provides estimates of the direct impacts of adoption before market adjustments occur (i.e., early adopter incentives). Second, quantifying overall market impacts of Zilmax® adoption and determining how costs and returns are distributed among industry sectors is essential for projecting probable success of the technology. Third, knowing how costs and returns of the technology will be distributed among industry sectors will help to identify sources of

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likely support for, or opposition against, industry adoption of the technology. We determine overall market impacts and distribution of impacts across industry sectors through use of an equilibrium displacement model (EDM).

Background

Zilpaterol hydrochloride is a synthetic beta adrenergic agonist (βAA) manufactured and sold by Intervet/Schering-Plough Animal Health (Intervet) under the product name Zilmax®. Synthetic beta agonists affect body composition in cattle, pigs, and poultry (Ricks, Baker, and Dalrymple, 1984). Zilpaterol hydrochloride has been approved for use in cattle feeding in Mexico and South Africa for more than fifteen years (Avendaño-Reyes et al., 2006). The United States Food and Drug Administration's Department of Health and Human Services approved its use for feeding to cattle in confinement in 2006 (U.S. Food and Drug Administration and U.S. Department of Health and Human Services).

Zilmax® is a feed additive prescribed for feeding to grain-fed cattle during the last few weeks of finishing. The feed additive is targeted by company sales representatives toward producers selling fed cattle on a grid pricing system. Feeding of Zilmax® for 20 days results in a 29-pound increase in typical steer carcasses (Hilton et al., 2010) and a 23-pound increase in heifer carcasses (Montgomery et al., 2009) relative to control cattle not fed Zilmax®. Essentially, feeding Zilmax® increases carcass meat deposition relative to fat and bone. The individual cattle feeder adopting the technology *ceteris paribus* experiences reduced carcass quality grade, improved yield grade, and increased potential for heavy-weight carcasses (Montgomery et al., 2009; Hutcheson, 2010). The net effect of feeding Zilmax® for cattle sold on a grid is that added revenue from heavier carcass weight plus improved yield grade more than offset revenue losses associated with reduced quality grade and the small increase in incidence of heavy-weight carcasses. For the packer, Zilmax® fed cattle exhibit increased red-meat yield, for any given yield grade (Hilton et al., 2010).

Zilmax® use also increases shear force measures of beef steaks (Brooks et al., 2009) raising concerns about potential impacts on product tenderness. Zilmax® fed cattle realize about 10 percentage points more (e.g., 15% compared to 5%) carcasses that yield 14-day aged steak products with greater than 4.5 kg Warner-Bratzler Shear Force values (indicating the threshold from tender to tough).[1] However, despite this finding, consumer sensory ratings of both tenderness and overall acceptability reveal essentially no difference between steaks from Zilmax® fed cattle and controls. In a sensory study with 564 consumers, more than 94% of consumers rated steaks from Zilmax® cattle as *acceptable* and more than 92% rated the beef as *acceptable for tenderness* compared to 91% *acceptable* and 90% *acceptable for tenderness* for control cattle not fed Zilmax® (Hilton et al., 2009). Research by Mehaffey et al. (2009), based on 766 consumers across four different cities, generally confirms these results.

Model

To determine the market effects of Zilmax® adoption, we utilize an equilibrium displacement model (EDM). EDMs are often used for analyzing market impacts of technology adoption and policy changes (e.g., Balagtas and Kim, 2007; Pendell et al., 2010; Brester, Marsh, and Atwood, 2004; Lemieux and Wohlgenant, 1989; Lusk and Anderson, 2004; Lusk and Norwood, 2005; Wohlgenant, 1993). We develop an EDM to simulate consumer and producer surplus impacts of Zilmax® being fed to U.S. beef cattle.

[1] Shackelford, Wheeler, and Koohmaraie (1999) concluded that a 4.6 kg WBSF was the threshold in moving from tender to tough steak. Platter et al. (2005) suggest a transition from slightly tender to slightly tough occurs at a threshold of WBSF of 4.4 kg.

The EDM is composed of four sectors in the beef industry: 1) retail (consumer), 2) wholesale (processor/packer), 3) slaughter (cattle feeding in feedlots), and 4) farm (feeder cattle from cow-calf producers). To capture interactions between retail meat substitutes for beef we also include the pork and poultry markets. Reflecting the higher degree of integration relative to the beef industry, the economic model includes three pork marketing chain sectors (retail, wholesale, and slaughter) and the poultry marketing chain is composed of two sectors (retail and wholesale). International trade is explicitly incorporated in the model at the wholesale level for all three species. The resulting framework is consistent with existing research and most closely follows the recent work of Brester, Marsh, and Atwood (2004) and Pendell et al. (2010). The structural model (omitting error terms for convenience) is given by the following series of general demand and supply equations of this multi-species model. Superscripts r, w, s, and f denote the retail, wholesale, slaughter, and farm market levels, respectively; subscripts B, K, and Y denote beef, pork, and poultry, respectively; P is price; Q is quantity; and Z and W denote demand and supply shifters, respectively. Consistent with existing international trade, the model captures imports (subscript i) and exports (subscript e) of beef, pork, and poultry.[2] Equations (1) - (25) omit superscripts for demand and supply as market clearing conditions are imposed, requiring demand and supply to equal.

Beef Marketing Chain

(1) Retail beef primary demand: $Q_B^r = f_1(P_B^r, P_K^r, P_Y^r, Z_B^r)$,

(2) Retail beef derived supply: $Q_B^r = f_2(P_B^r, Q_B^w, W_B^r)$,

(3) Wholesale beef derived demand: $Q_B^w = f_3(P_B^w, Q_B^r, Z_B^w)$,

(4) Wholesale beef derived supply: $Q_B^w = f_4(P_B^w, Q_B^s, Q_{Bi}^w, Q_{Be}^w, W_B^w)$,

(5) Imported wholesale beef derived demand: $Q_{Bi}^w = f_5(P_{Bi}^w, Q_B^w, Z_{Bi}^w)$,

(6) Imported wholesale beef derived supply: $Q_{Bi}^w = f_6(P_{Bi}^w, W_{Bi}^w)$,

(7) Exported wholesale beef derived demand: $Q_{Be}^w = f_7(P_B^w, Z_{Be}^w)$,

(8) Slaughter cattle derived demand: $Q_B^s = f_8(P_B^s, Q_B^w, Z_B^s)$,

(9) Slaughter cattle derived supply: $Q_B^s = f_9(P_B^s, Q_B^f, W_B^s)$,

(10) Farm (feeder cattle) derived demand: $Q_B^f = f_{10}(P_B^f, Q_B^s, Z_B^f)$,

(11) Farm (feeder cattle) primary supply: $Q_B^f = f_{11}(P_B^f, W_B^f)$,

Pork Marketing Chain

(12) Retail pork primary demand: $Q_K^r = f_{12}(P_B^r, P_K^r, P_Y^r, Z_K^r)$,

(13) Retail pork derived supply: $Q_K^r = f_{13}(P_K^r, Q_K^w, W_K^r)$,

(14) Wholesale pork derived demand: $Q_K^w = f_{14}(P_K^w, Q_K^r, Z_K^w)$,

(15) Wholesale pork derived supply: $Q_K^w = f_{15}(P_K^w, Q_K^s, Q_{Ki}^w, Q_{Ke}^w, W_K^w)$,

(16) Imported wholesale pork derived demand: $Q_{Ki}^w = f_{16}(P_{Ki}^w, Q_K^w, Z_{Ki}^w)$,

(17) Imported wholesale pork derived supply: $Q_{Ki}^w = f_{17}(P_{Ki}^w, W_{Ki}^w)$,

(18) Exported wholesale pork derived demand: $Q_{Ke}^w = f_{18}(P_K^w, Z_{Ke}^w)$,

(19) Slaughter hog derived demand: $Q_K^s = f_{19}(P_K^s, Q_K^w, Z_K^s)$,

(20) Slaughter hog primary supply: $Q_K^s = f_{20}(P_K^s, W_K^s)$,

[2] This model follows Pendell et al. (2010) and similar studies in assuming international trade can be succinctly captured by including exchange of meat products while not explicitly incorporating live animal trade. As noted by a reviewer, future research could expand on this approach to consider both meat and live animal components.

Poultry Marketing Chain

(21) Retail poultry primary demand: $Q_Y^r = f_{21}(P_B^r, P_K^r, P_Y^r, Z_Y^r)$,

(22) Retail poultry derived supply: $Q_Y^r = f_{22}(P_Y^r, Q_Y^w, Q_{Ye}^r, W_Y^r)$,

(23) Wholesale poultry derived demand: $Q_Y^w = f_{23}(P_Y^w, Q_Y^r, Z_Y^w)$,

(24) Wholesale poultry primary supply: $Q_Y^w = f_{24}(P_Y^w, W_Y^w)$,

(25) Exported wholesale poultry derived demand: $Q_{Ye}^w = f_{25}(P_Y^w, Z_{Ye}^w)$,

Consistent with Wohlgenant (1993), we incorporate variable input proportions by allowing production quantities to vary across the market levels in the marketing chain. Totally differentiating equations (1) - (25), including variable input proportions, and placing all the endogenous variables on the left-hand side of each equation and isolating exogenous effects to the right-hand side of each equation results in the following EDM. E represents a relative change operator (i.e., $EQ = d\ln Q = dQ/Q$); η_a^m is the own-price elasticity of meat/species a demand at market level m; η_{ab}^m is the cross-price elasticity of demand for meat a with respect to retail prices of meat b; ε_a^m is the own-price elasticity of meat/species a supply at market level m; τ^{lm} is the percentage change in quantity demanded at market level m given a 1% change in quantity demanded at market level l; γ^{lm} is the percentage change in quantity supplied at market level m given a 1% change in quantity supplied at market level l. In this specification, market levels are linked by downstream quantity variables among the demand equations and upstream quantity variables among the supply equations (Wohlgenant, 1993).

Beef Marketing Chain

(1') Retail beef primary demand: $EQ_B^r - \eta_B^r EP_B^r - \eta_{BK}^r EP_K^r - \eta_{BY}^r EP_Y^r = EZ_B^r$,

(2') Retail beef derived supply: $EQ_B^r - \varepsilon_B^r EP_B^r - \gamma_B^{wr} EQ_B^w = EW_B^r$,

(3') Wholesale beef derived demand: $EQ_B^w - \eta_B^w EP_B^w - \tau_B^{rw} EQ_B^r = EZ_B^w$,

(4') Wholesale beef derived supply: $EQ_B^w - \varepsilon_B^w EP_B^w - \gamma_B^{sw}(Q_B^s/Q_B^w)EQ_B^s -$
$(Q_{Bi}^w/Q_B^w)EQ_{Bi}^w + (Q_{Be}^w/Q_B^w)EQ_{Be}^w = EW_B^w$,

(5') Imported wholesale beef derived demand: $EQ_{Bi}^w - \eta_{Bi}^w EP_{Bi}^w - \tau_B^{rw} EQ_B^w =$
$(Q_{Bi}^w/Q_B^w)EZ_{Be}^w + EZ_{Bi}^w$,

(6') Imported wholesale beef derived supply: $EQ_{Bi}^w - \varepsilon_{Bi}^w EP_{Bi}^w = EW_{Bi}^w$,

(7') Exported wholesale beef derived demand: $EQ_{Be}^w - \eta_{Be}^w EP_B^w = EZ_{Be}^w$,

(8') Slaughter cattle derived demand: $EQ_B^s - \eta_B^s EP_B^s - \tau_B^{ws} EQ_B^w =$
$(Q_{Be}^w/Q_B^w)EZ_{Be}^w + EZ_B^s$,

(9') Slaughter cattle derived supply: $EQ_B^s - \varepsilon_B^s EP_B^s - \gamma_B^{fs} EQ_B^f = EW_B^s$,

(10') Farm (feeder cattle) derived demand: $EQ_B^f - \eta_B^f EP_B^f - \tau_B^{sf} EQ_B^s = EZ_B^f$,

(11') Farm (feeder cattle) primary supply: $EQ_B^f - \varepsilon_B^f EP_B^f = EW_B^f$, *Pork Marketing Chain*

(12') Retail pork primary demand: $EQ_K^r - \eta_{KB}^r EP_B^r - \eta_K^r EP_K^r - \eta_{KY}^r EP_Y^r = EZ_K^r,$

(13') Retail pork derived supply: $EQ_K^r - \varepsilon_K^r EP_K^r - \gamma_K^{wr} EQ_K^r = EW_K^r,$

(14') Wholesale pork derived demand: $EQ_K^w - \eta_K^w EP_K^w - \tau_K^{rw} EQ_K^r = EZ_K^w,$

(15') Wholesale pork derived supply: $EQ_K^w - \varepsilon_K^w EP_K^w - \gamma_K^{sw}(Q_K^s/Q_K^w)EQ_K^s - (Q_{Ki}^w/Q_K^w)EQ_{Ki}^w + (Q_{Ke}^w/Q_K^w)EQ_{Ke}^w = EQ_K^w,$

(16') Imported wholesale pork derived demand: $EQ_{Ki}^w - \eta_{Ki}^w EP_{Ki}^w - \tau_K^{rw} EQ_K^w = (Q_{Ki}^w/Q_K^w)EZ_{Ke}^w + EZ_{Ki}^w,$

(17') Imported wholesale pork derived supply: $EQ_{Ki}^w - \varepsilon_{Ki}^w EP_{Ki}^w = EW_{Ki}^w,$

(18') Exported wholesale pork derived demand: $EQ_{Ke}^w - \eta_{Ke}^w EP_K^w = EZ_{Ke}^w,$

(19') Slaughter hog derived demand: $EQ_K^s - \eta_K^s EP_K^s - \tau_K^{ws} EQ_K^w = (Q_{Ke}^w/Q_K^w)EZ_{Ke}^w + EZ_K^s,$

(20') Slaughter hog primary supply: $EQ_K^s - \varepsilon_K^s EP_K^s = EW_K^s,$

Poultry Marketing Chain

(21') Retail poultry primary demand: $EQ_Y^r - \eta_{YB}^r EP_B^r - \eta_{YK}^r EP_K^r - \eta_Y^r EP_Y^r = EZ_Y^r,$

(22') Retail poultry derived supply: $EQ_Y^r - \varepsilon_Y^r EP_Y^r - \gamma_Y^{wr} EQ_Y^w = EW_Y^r,$

(23') Wholesale poultry derived demand: $EQ_Y^w - \eta_Y^w EP_Y^w - \tau_Y^{rw} EQ_Y^r = EZ_Y^w,$

(24') Wholesale poultry primary supply: $EQ_Y^w - \varepsilon_Y^w EP_Y^w + (Q_{Ye}^w/Q_Y^w)EQ_{Ye}^w = EQ_Y^w,$

(25') Exported wholesale poultry derived demand: $EQ_{Ye}^w - \eta_{Ye}^w EP_Y^w = EZ_{Ye}^w,$

Balagtas and Kim (2007) note this model can be expressed in matrix form as $\boldsymbol{RY} = \boldsymbol{Z}$, where R is a matrix of model parameters (i.e., elasticities), $\boldsymbol{Y}$ is a column vector of endogenous changes in prices and quantities relative to an initial equilibrium, and $\boldsymbol{Z}$ is a column vector of percentage changes associated with introducing Zilmax®. The model defines proportional changes in equilibrium prices and quantities for each evaluated market level and species in response to exogenous changes corresponding to Zilmax® introduction. These proportional changes are identified as:

(26) $$\boldsymbol{Y} = \boldsymbol{R}^{-1}\boldsymbol{Z}.$$

We use consumer and producer surplus to quantify the net economic impact of Zilmax® adoption. Changes in consumer and producer surplus created by introducing Zilmax® can be calculated in terms of changes in prices and quantities identified by the EDM as:

(27) $$\Delta CS_a = P_a^r Q_a^r (EP_a^r - EZ_a^r)(1 + 0.5EQ_a^r),$$

(28) $$\Delta PS_a^m = P_a^m Q_a^m (EP_a^m + EW_a^m)(1 + 0.5EQ_a^m),$$

where consumer and producer surplus are denoted by CS and PS, respectively (Lusk and Anderson, 2004). The superscript m denotes the market level (i.e., r = retail, w = wholesale (processor/packer), s = slaughter (feeding), and f = feeder (farm level)) and subscript a denotes the industry/species evaluated (i.e., beef, pork, or poultry). Change in total producer surplus is the sum of the change in producer surplus from each market level for a species, $\Delta PS_a = \sum_m \Delta PS_a^m$. Similarly, total changes in meat industry producer and consumer surplus are given by $\Delta PS = \sum_m \sum_a \Delta PS_a^m$ and $\Delta CS = \sum_a \Delta CS_a$, respectively.

Solutions to equation (26) require elasticity estimates for the matrix of parameters (***R***). Identifying these estimates by econometrically estimating structural supply and demand equations for the 25-equation EDM is problematic. As in most EDM applications, direct estimation of elasticities is prohibited by the large number of equations and by identification problems in jointly estimating supply and demand relationships (Brester, Marsh, and Atwood, 2004). However, given Zilmax® adoption results in relatively small aggregate market shifts (in proportional terms), we follow standard EDM procedures and utilize elasticity estimates reported in the published literature.

To capture the dynamic nature of adjustments to livestock and meat markets after the adoption of Zilmax®, we simulate our model annually for ten consecutive years. Consistent with historical beef cattle cycles, we assume that it takes the marketplace ten years to fully adjust from short-run to long-run relationships.[3] Ten years of market effects were simulated by linearly adjusting all elasticities between short-run (year 1) and long-run (year 10) using elasticity estimates employed by Pendell et al. (2010).[4] The supply, demand, and quantity transmission elasticities are summarized in appendix tables A1 and A2. Similarly, base price and quantity values are necessary to estimate surplus calculations. The market price and quantity values are summarized in appendix table A3 and each reflects annual average values for calendar year 2009 as reported by the Livestock Marketing Information Center (LMIC).

In investigating aggregate market effects, our analysis reflects Zilmax® use on 5% of fed cattle in year 1, 9% in year 2, and 12% in year 3, which mirrors actual adoption rates in 2009 and 2010 and forecasted adoption rates for 2011 (Yates, 2011).[5] Beginning in year 4 and continuing through year 10, we assume that Zilmax® use is constant at a rate of 20%, reflecting projected 2012 adoption rates (Yates, 2011). The upper limit of 20% adoption, which is likely a conservative low estimate given it is held fixed through year 10, assumes about one-half of fed cattle currently sold on a grid would adopt Zilmax®.

Results

When producers adopt Zilmax® in finishing cattle, there are two important exogenous impacts that are initial shocks to the EDM. First, production costs decline, leading to an outward shift in fed cattle supply. Second, packers realize increased red meat yield, resulting in an outward shift in wholesale beef supply. These two initial exogenous shocks are the impetus for numerous other endogenous shifts that follow in the EDM.

The change in net return of finishing cattle for those that adopt Zilmax® feeding was estimated first. Gross return was calculated as increased weight gain multiplied by the grid price adjusted for expected change in quality grade, yield grade, and heavy-weight carcasses associated with Zilmax® feeding. From gross return we deducted the cost of Zilmax®, giving a net return change. Calculations were made using average prices and grid premiums and discounts for 2009. Fed cattle dressed price data and grid premiums and discounts were based on USDA data obtained from LMIC. The cost of Zilmax® was calculated using the formula provided at http://www.Zilmax.com/customerpricing.aspx. During 2009, the average cost of feeding Zilmax® for 20 days at the prescribed rate was about $18 per head.

Hilton et al. (2010) analyzed data from seven different studies where Zilmax® was fed for 0, 20, 30, and 40 days prior to harvest, comprising a total of 11,877 head of beef steers. We used data compiled by Hodgen from the Hilton et al. (2010) study that is based on the 0 (control) and 20-day (Zilmax®-fed) treatments to determine changes in carcass weight and quality and yield grades. Twenty-day Zilmax®-fed steers produced carcasses weighing 884 pounds compared to carcasses from the control group, which weighed 855 pounds, or 29 additional pounds. Heifer carcasses

[3] As noted by a reviewer, cattle cycles vary in length, but the average is typically considered to be about 10 years in length (Marsh, 1999).

[4] Available at: http://ajae.oxfordjournals.org/content/suppl/2010/04/29/aaq037.DC1/aaq037supp.pdf

[5] Zilmax® was approved for use in cattle feeding in August 2006. Our model starts assessing economic impact (what we refer to as year 1) once product production and marketing programs were established starting in 2009.

Table 1. Exogenous Cattle and Beef Marketing Chain Supply Shifters Corresponding to Zilmax® Use

Cost reductions associated with producing:	Year 1 5% Adoption	Year 2 9% Adoption	Year 3 12% Adoption	Years 4-10 20% Adoption
Retail beef	0.000%	0.000%	0.000%	0.000%
Wholesale beef	0.149%	0.269%	0.358%	0.597%
Slaughter cattle	0.099%	0.179%	0.238%	0.397%
Feeder cattle	0.000%	0.000%	0.000%	0.000%

gained 23 additional pounds when fed Zilmax® for 20 days (Montgomery et al., 2009). Data from Hodgen indicate Zilmax® cattle relative to the control 1) have about a 20 percentage point greater incidence of being yield grade 1 or 2 with a similar reduction in being yield grade 3.5 or poorer, 2) have approximately an 11 percentage point reduction in quality grading Choice or higher, and 3) have a 2 percentage point increase in carcasses weighing in excess of 1,000 pounds (i.e., heavy-weight carcass discount applied).[6] The estimated net return associated with Zilmax® feeding was $24.24/head for steers and $15.69/head for heifers during 2009. Feedlot inventories are assumed to be 63% steers and 37% heifers (LMIC) resulting in a feedlot weighted-average benefit of $21.08/head for feeding Zilmax®.

To determine the exogenous shock of Zilmax® on the wholesale supply function, we utilized carcass cutout data from Hilton et al. (2010) comprising 3,496 steers fed Zilmax® for 20 days and 3,542 steers from a control group that was not fed Zilmax®. Beef product cut yields for 33 fabricated carcass products (including trim, bone, and fat) were obtained from stratified samples of 263 control and 538 Zilmax®-fed carcasses. Fabricated cut yield and associated quality and yield grade data were obtained from Hodgen. Prices for each fabricated cut for each of five quality grades (Prime, Branded, Choice, Select, and Ungraded) were collected from USDA.[7] The prices were multiplied by respective red meat yields for each quality grade of the Zilmax®-fed and control carcasses with the difference between these used to obtain a gross revenue enhancement for packers that slaughter Zilmax®-fed cattle. The cost of the cattle estimated from the gross return to cattle feeders (discussed above) was deducted from the packer gross revenue to obtain net revenue. Net return benefits for packers slaughtering Zilmax® fed cattle were $32.92/head for steers and $29.57/head for heifers, for a combined weighted-average net return of $31.68 per head slaughtered (63% steers and 37% heifers (LMIC)).

The incremental net returns to feedlots that feed Zilmax® ($21.08/head) and packers that buy Zilmax® fed cattle ($31.68/head) were used as exogenous shocks increasing fed cattle and wholesale beef supply in the EDM. The effects of Zilmax® were introduced into the model by shocking EW_B^w and EW_B^s in equations (4') and (9'). The specific values utilized for live animal market segments (feedlot and packer) were proportions of the net returns per head divided by $1,061, which was the average total value of a slaughter animal in 2009. For instance, when considering 20% adoption of Zilmax® (assumed for years 4-10), the shocks are calculated as $EW_B^w = 0.6 - \%(\$31.68/\$1,061 \times 0.2)$, and $EW_B^s = 0.40\%(\$21.08/\$1,061 \times 0.2)$. These values are presented in table 1. As indicated by the 0% values in table 1, we assumed no additional direct net return benefits of Zilmax® in that our EDM does not include direct cost of production reductions for feeder cattle or retail beef production. We also assumed no direct demand impacts of Zilmax® adoption.

Table 2 presents a summary of percentage changes in livestock and meat prices and quantities, derived using equation (26), resulting from Zilmax® adoption relative to a base of 0% use. The market impacts of the adjustments are intuitive and consistent with Zilmax® adoption introducing

[6] Detailed quality grade and yield grade distributions for Zilmax®-fed and control cattle are available from the authors upon request.

[7] Weekly USDA price reports were used to compile prices for each of the 33 fabricated beef products for each of the five quality grades. The reports were all accessed at the USDA Data Mart available at: http://mpr.datamart.ams.usda.gov. Specific USDA price reports used included: LM_XB452; LM_XB456; LM_XB459; LM_XB460; LM_XB461; and LM_XB462.

supply shocks at the slaughter (feedlot) and wholesale (packer) level. Increased net returns to producer adopters of Zilmax® cause slaughter cattle supply to shift rightward. Likewise, packers who accept cattle fed Zilmax® realize increased red meat yields, shifting wholesale beef supply to the right. Increases in slaughter cattle and wholesale beef supply increase derived supply of retail beef. Likewise, the quantity of feeder cattle demanded at the farm level also increases.

Quantities at all four market levels in the cattle and beef marketing chain increase, prices decline at the retail and wholesale beef levels, and feeder cattle prices increase for all 10 years. This is a result of Zilmax® adoption increasing cattle feeder and beef packer supplies and increasing the quantity of feeder cattle demanded by feedlots. The impacts of Zilmax® adoption on prices and quantities are notably larger in years 1-4 when supply is inelastic. As supply becomes more elastic and more able to adjust, the impacts decline. For instance, wholesale beef quantities increase by 2.13%, 1.98%, and 0.94% in years 1, 2, and 3 but only increase by 0.33% or less after year 7. Similarly, feeder cattle prices increase by 4.18% and 2.55% in years 1 and 2 but increase by 0.14% or less from year 8 forward.

Using equations (26) and (27), we calculated the economic welfare impacts of Zilmax® adoption. Table 3 presents producer and consumer surplus estimates identified by the EDM for each of the ten years. The short-run impacts (1 year) are much larger than the long-run impacts (10 year). This is expected because long-run supply is more elastic than short-run supply. Table 3 also presents ten-year cumulative present values (using a 5% discount rate) of changes in producer and consumer surplus measures.

Overall, beef industry producers and consumers benefit from Zilmax® introduction. The ten-year cumulative present value of beef industry producer surplus is $317 million and beef consumers gain $2.34 billion in surplus. Combining all surplus measures of producers and consumers across beef, pork, and poultry, the cumulative ten-year present value is a surplus gain of $2.61 billion.

The cow-calf (feeder cattle) production segment is the largest beneficiary of Zilmax® introduction in the beef production sector, because derived demand for feeder cattle is enhanced by cost reductions occurring at feedlot and packer levels. The cumulative ten-year present value of Zilmax® introduction is $2.28 billion for feeder cattle producers. As such, feeder cattle producers are likely to support Zilmax® adoption at feedlots, as they would support any technology that enhances downstream production efficiency. Slaughter cattle producers also gain surplus in each year with a cumulative ten-year present value estimated at $1.48 billion. The cost reductions that feedlots enjoy from adopting Zilmax® provide feedlots direct benefits that are not fully passed back to cow-calf producers through higher feeder cattle prices. Beef wholesale producers lose about $1.1 billion over the 10-year period. The beef retail producer sector realizes losses that equal retail beef consumer gains of $2.3 billion.[8]

As table 3 reveals, cumulative losses at the wholesale producer sector as well as large gains in consumer sectors result mostly from impacts in years 1-5. As the entire meat and livestock marketing chain adjusts to new market conditions in later years, beef packers actually begin to gain surplus. That is, Zilmax® introduction is detrimental to overall wholesale producer welfare in years 1-5 but increasingly beneficial in years 6-10. Similarly, the retail producer sector loses much less surplus in later years than during the first few years of Zilmax® adoption. To further understand how the retail and wholesale beef levels are negatively impacted, recall the increases in quantities enhance producer surplus for both retail and wholesale beef producers (see equation 28). However, reductions in retail and wholesale beef prices for years 1-5 (table 2) exceed exogenous shocks presented by Zilmax® introduction. For example, in year 1 wholesale beef prices decline by 1.70% (table 2) and a positive exogenous shift of 0.15% (table 1) is introduced to correspond

[8] Unpublished research suggests retail meat yields may also increase a small amount for selected beef products harvested from Zilmax® fed cattle (Yates, 2010). Because these findings have not been finalized, we assume no supply shift occurs at retail from Zilmax® adoption. As such, the retail sector could realize small surplus gains from Zilmax® adoption that we did not estimate.

Table 2. Percentage Change in Endogenous Variables of the Equilibrium Displacement Model

Endogenous Variables	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Retail beef quantity	1.15%	0.79%	0.30%	0.24%	0.15%	0.10%	0.08%	0.06%	0.05%	0.04%
Retail beef price	-1.36%	-0.89%	-0.32%	-0.25%	-0.15%	-0.10%	-0.07%	-0.05%	-0.04%	-0.04%
Retail pork price	-0.09%	-0.04%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Retail poultry price	-0.18%	-0.02%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Wholesale beef quantity	2.13%	1.98%	0.94%	0.89%	0.62%	0.47%	0.39%	0.33%	0.29%	0.27%
Wholesale beef price	-1.70%	-1.93%	-0.97%	-0.93%	-0.64%	-0.48%	-0.38%	-0.32%	-0.27%	-0.24%
Slaughter cattle quantity	1.57%	1.92%	1.02%	1.03%	0.74%	0.58%	0.49%	0.42%	0.38%	0.34%
Imported wholesale beef quantity	1.61%	1.61%	0.79%	0.77%	0.54%	0.42%	0.35%	0.30%	0.27%	0.24%
Exported wholesale beef quantity	0.71%	1.37%	0.96%	1.19%	1.00%	0.89%	0.82%	0.78%	0.74%	0.71%
Imported wholesale beef price	0.88%	0.59%	0.22%	0.17%	0.10%	0.07%	0.05%	0.04%	0.03%	0.02%
Slaughter cattle price	1.88%	0.59%	0.01%	-0.14%	-0.15%	-0.14%	-0.13%	-0.12%	-0.11%	-0.10%
Feeder cattle quantity	0.92%	1.30%	0.73%	0.75%	0.55%	0.43%	0.37%	0.32%	0.29%	0.26%
Feeder cattle price	4.18%	2.55%	0.91%	0.69%	0.40%	0.26%	0.19%	0.14%	0.11%	0.09%
Retail pork quantity	-0.18%	-0.13%	-0.05%	-0.04%	-0.02%	-0.02%	-0.01%	-0.01%	-0.01%	-0.01%
Wholesale pork quantity	-0.12%	-0.10%	-0.04%	-0.03%	-0.02%	-0.01%	-0.01%	-0.01%	-0.01%	-0.01%
Wholesale pork price	-0.09%	-0.05%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Slaughter hogs quantity	-0.05%	-0.05%	-0.02%	-0.02%	-0.01%	-0.01%	-0.01%	-0.01%	0.00%	0.00%
Imported wholesale pork quantity	-0.08%	-0.07%	-0.03%	-0.03%	-0.02%	-0.01%	-0.01%	-0.01%	-0.01%	-0.01%
Exported wholesale pork quantity	0.08%	0.04%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Imported wholesale pork price	-0.06%	-0.03%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Slaughter hogs price	-0.13%	-0.08%	-0.03%	-0.02%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%
Retail poultry quantity	-0.20%	-0.16%	-0.06%	-0.04%	-0.03%	-0.02%	-0.01%	-0.01%	-0.01%	-0.01%
Wholesale poultry quantity	-0.20%	-0.16%	-0.06%	-0.05%	-0.03%	-0.02%	-0.01%	-0.01%	-0.01%	-0.01%
Wholesale poultry price	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Exported wholesale poultry quantity	1.34%	1.06%	0.39%	0.30%	0.18%	0.12%	0.09%	0.07%	0.05%	0.04%

Notes: Percentage changes are relative to a base of 0% Zilmax® use assuming it is used on 5%, 9%, 12%, and 20% of slaughter cattle in years 1, 2, 3, and 4-10, respectively.

with 5% Zilmax® adoption. This price decline exceeds the supply shift impact, resulting in a negative wholesale beef surplus. Conversely, for years 6-10 the reductions in wholesale beef prices are less than corresponding exogenous supply shifts introduced by 20% Zilmax® usage, resulting in positive producer surplus.

Zilmax® adoption increases quantities of retail beef and decreases quantities of retail pork and poultry in each of the 10 years. Moreover, estimated reductions in retail beef prices are larger (i.e., -1.36% in year 1) than corresponding changes in both retail pork and poultry prices (i.e., -0.09% and -0.18% in year 1). These retail level adjustments reduce retail producer surplus because retail derived supply increases from Zilmax® adoption (see table 1 and footnote 8). The retail supply increase results in reductions in retail prices (table 2), leading to negative retail producer surplus (see equation 28). In contrast, these retail price and quantity adjustments correspond to Zilmax® increasing the cumulative ten-year present value of total meat consumer surplus by $2.49 billion (table 3). This increased consumer surplus is largely attributable to retail beef ($2.34 billion) with consumer pork and poultry surplus increasing more modestly ($62 and $84 million, respectively). Pork and poultry consumers benefit from Zilmax® adoption primarily by being able to substitute cheaper retail beef for pork and poultry. Because demand for pork and for poultry is inelastic, reductions in demand caused by cheaper beef result in gains in pork and poultry consumer surpluses. For context, the cumulative consumer surplus increase of $2.49 billion equates approximately to a ten-year benefit of $8.11/person given a United States resident population of 307 million in 2009 (LMIC).

Conclusions

New production technologies face a number of challenges as they are introduced. In addition to determining how to encourage producer adoption, manufacturers of the new technology can also be challenged by the reluctance of industry sectors to accept the technology. Encouraging producers to adopt the technology first requires demonstrating direct economic benefits to early adopters.

Zilmax® offers economically significant returns to early adopters. For cattle feeders, added net returns to Zilmax® adopters are about $21/head. Long-run cattle feeding returns average only about $15/head (Mark, Schroeder, and Jones, 2000), so Zilmax® adoption doubles representative net returns for early feedlot adopters. In addition to producer returns, beef packers also realize added net returns from slaughtering Zilmax® fed cattle because of increased red meat yields. Beef packers realize more than a $31/head increase in net return from being an early adopter slaughtering Zilmax® fed cattle. Koontz and Lawrence (2010) estimate beef packer average profit per head slaughtered at a loss of $2.40/head over October 2002 through March 2005. Thus, Zilmax® fed cattle offer a substantial direct benefit to beef packers that are willing to buy adopters' cattle.

Longer-term market effects of Zilmax® adoption to the cattle and beef industry reveal that the ultimate beneficiaries of this technology are cow-calf producers and consumers as the benefits from feedlots and packers are transmitted through the rest of the market system. Over ten years, cow-calf producer welfare increases by a cumulative net present value (NPV) of $2.28 billion. Similarly, consumers gain a cumulative NPV of $2.49 billion over ten years. Cattle feeders gain $1.48 billion, beef packers lose $1.10 billion, and retailers lose $2.34 billion cumulative NPV over ten years.

An interesting question is why some producers and packers have resisted adoption. Returns to these sectors for early adopters and well as for long-run adoption are substantial. Addressing the issue of partial Zilmax® adoption is left for future research. We suspect reluctance to adopt by some industry participants could be related to concerns about potential reduction in beef demand. Some may perceive adverse consumer reaction to feeding of beta agonists in general or possibly are concerned with meat tenderness reductions associated with Zilmax® fed cattle. Research to date suggests tenderness impacts should not be of significant concern (Delmore, Hodgen, and Johnson, 2010), but we are unaware of broader assessments of consumer acceptance of synthetic

Table 3. Producer and Consumer Surplus Changes from Zilmax® Adoption ($ millions)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Cumulative Present Value
Beef Producer Surplus											
Retail level	-1,098.21	-715.56	-260.31	-200.96	-117.49	-77.84	-56.44	-43.19	-34.40	-28.26	-2,344.14
Wholesale level	-572.01	-612.33	-225.81	-122.37	-15.12	42.80	77.69	101.48	118.26	131.09	-1,095.21
Slaughter cattle level	709.78	275.49	88.44	92.95	87.27	90.05	94.14	97.96	101.66	104.84	1,477.41
Feeder cattle level	1,119.65	683.56	242.36	184.50	106.23	69.77	50.11	38.05	30.17	24.54	2,278.67
Total Beef Industry Producer Surplus	159.21	-368.84	-155.32	-45.88	60.89	124.79	165.50	194.30	215.68	232.21	316.72
Pork Producer Surplus											
Retail level	-42.05	-16.41	-3.98	-2.20	-0.96	-0.50	-0.29	-0.19	-0.13	-0.09	-61.79
Wholesale level	-11.41	-6.04	-1.78	-1.11	-0.53	-0.30	-0.18	-0.12	-0.08	-0.06	-19.74
Slaughter hog level	-16.6	-11.13	-3.84	-2.78	-1.50	-0.92	-0.62	-0.44	-0.33	-0.25	-34.48
Total Pork Industry Producer Surplus	-70.06	-33.58	-9.60	-6.09	-3.00	-1.72	-1.10	-0.75	-0.54	-0.40	-116.01
Poultry Producer Surplus											
Retail level	-78.74	-6.93	-1.36	-0.71	-0.32	-0.17	-0.10	-0.07	-0.05	-0.03	-83.58
Wholesale level	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Total Poultry Industry Producer Surplus	-78.74	-6.93	-1.36	-0.71	-0.32	-0.17	-0.10	-0.07	-0.05	-0.03	-83.58
Total Meat Industry Producer Surplus	10.41	-409.35	-166.28	-52.69	57.58	122.90	164.30	193.48	215.10	231.78	117.13
Consumer Surplus											2,344.14
Retail Beef	1,098.21	715.56	260.31	200.96	117.49	77.84	56.44	43.19	34.40	28.26	61.79
Retail Pork	42.05	16.41	3.98	2.20	0.96	0.50	0.29	0.19	0.13	0.09	83.58
Retail Poultry	78.74	6.93	1.36	0.71	0.32	0.17	0.10	0.07	0.05	0.03	2,489.51
Total Meat Consumer Surplus	1,219.00	738.90	265.65	203.87	118.77	78.51	56.83	43.44	34.58	28.38	

Notes: These percentage changes are relative to a base of 0% Zilmax® use assuming it is used on 5%, 9%, 12%, and 20% of slaughter cattle in years 1, 2, 3, and 4-10, respectively.

beta adrenergic agonists in livestock production.[9] Whatever the reasons, in the meantime, relatively low adoption is enhancing benefits to producer and packer adopters. Partial adoption and diverse economic welfare impacts highlighted in this study are likely to sustain discussions on the role of Zilmax® and related technologies in modern livestock production.

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Appendix A: EDM Parameters

Table A1. Supply and Demand Elasticity Definitions and Estimates

Definition	Short-Run Estimate	Long-Run Estimate
Own-price elasticity of demand for retail beef	-0.86	-1.17
Own-price elasticity of supply for retail beef	0.36	4.62
Own-price elasticity of demand for wholesale beef	-0.58	-0.94
Own-price elasticity of supply for wholesale beef	0.28	3.43
Own-price elasticity of demand for wholesale beef imports	-0.58	-0.94
Own-price elasticity of supply for wholesale beef imports	1.83	10.00
Own-price elasticity of demand for wholesale beef exports	-0.42	-3.00
Own-price elasticity of demand for slaughter cattle	-0.40	-0.53
Own-price elasticity of supply for slaughter cattle	0.26	3.24
Own-price elasticity of demand for feeder cattle	-0.14	-0.75
Own-price elasticity of supply for feeder cattle	0.22	2.82
Cross-price elasticity of demand for retail beef with respect to the price of retail pork	0.10	0.10
Cross-price elasticity of demand for retail beef with respect to the price of retail poultry	0.05	0.05
Own-price elasticity of demand for retail pork	-0.69	-1.00
Own-price elasticity of supply for retail pork	0.73	3.87
Own-price elasticity of demand for wholesale pork	-0.71	-1.00
Own-price elasticity of supply for wholesale pork	0.44	1.94
Own-price elasticity of demand for wholesale pork imports	-0.71	-1.00
Own-price elasticity of supply for wholesale pork imports	1.41	10.00
Own-price elasticity of demand for wholesale pork exports	-0.89	-1.00
Own-price elasticity of demand for slaughter hogs	-0.51	-1.00
Own-price elasticity of supply for slaughter hogs	0.41	1.80
Cross-price elasticity of demand for retail pork with respect to the price of retail beef	0.18	0.18
Cross-price elasticity of demand for retail pork with respect to the price of retail poultry	0.02	0.02
Own-price elasticity of demand for retail poultry	-0.29	-1.00
Own-price elasticity of supply for retail poultry	0.18	13.10
Own-price elasticity of demand for wholesale poultry	-0.22	-1.00
Own-price elasticity of supply for wholesale poultry	0.14	14.00
Own-price elasticity of demand for wholesale poultry exports	-0.31	-1.00
Cross-price elasticity of demand for retail poultry with respect to the price of retail beef	0.18	0.18
Cross-price elasticity of demand for retail poultry with respect to the price of retail pork	0.04	0.04

Notes: All supply and demand elasticity estimates correspond to those used by Pendell et al. (2010). Short-run and long-run refer to years 1 and 10, respectively.

Table A2. Quantity Transmission Elasticity Definitions and Estimates

Definition	Estimate
Percentage change in retail beef supply given a 1% change in wholesale beef supply	0.771
Percentage change in wholesale beef supply given a 1% change in slaughter cattle supply	0.909
Percentage change in slaughter cattle supply given a 1% change in feeder cattle supply	1.070
Percentage change in wholesale beef demand given a 1% change in retail beef demand	0.995
Percentage change in slaughter cattle demand given a 1% change in wholesale beef demand	1.090
Percentage change in feeder cattle demand given a 1% change in slaughter cattle demand	0.957
Percentage change in retail pork supply given a 1% change in wholesale pork supply	0.962
Percentage change in wholesale pork supply given a 1% change in slaughter hogs supply	0.963
Percentage change in retail pork supply given a 1% change in wholesale pork supply	0.962
Percentage change in slaughter hogs demand given a 1% change in wholesale pork demand	0.961
Percentage change in retail poultry supply given a 1% change in wholesale poultry supply	0.806
Percentage change in retail poultry supply given a 1% change in wholesale poultry supply	1.035

Notes: All quantity transmission elasticity estimates correspond to those used by Pendell et al. (2010).

Table A3. Price and Quantity Definitions and Estimates

Definition	Estimate
Quantity of retail beef, billion pounds (retail weight)	18.788
Quantity of wholesale beef, billion pounds (carcass weight)	25.963
Quantity of beef obtained from slaughter cattle, billion pounds (live weight)	42.659
Quantity of wholesale beef imports, billion pounds (carcass weight)	2.626
Quantity of wholesale beef exports, billion pounds (carcass weight)	1.868
Quantity of beef obtained from feeder cattle, billion pounds (live weight)	27.390
Price of retail (Choice) beef, cents per pound	425.975
Price of wholesale (Choice) beef, cents per pound	140.575
Price of wholesale beef imports, cents per pound	149.920
Price of slaughter cattle, $/cwt (live weight)	83.250
Price of feeder cattle, $/cwt	97.280
Quantity of retail pork, billion pounds (retail weight)	15.378
Quantity of wholesale pork, billion pounds (carcass weight)	22.949
Quantity of pork obtained from slaughter hogs, billion pounds (live weight)	30.669
Quantity of wholesale pork imports, billion pounds (carcass weight)	0.833
Quantity of wholesale pork exports, billion pounds (carcass weight)	4.126
Price of retail pork cents per pound	291.975
Price of wholesale pork, cents per pound	58.190
Price of wholesale pork imports, cents per pound	36.585
Price of slaughter hogs, $/cwt (live weight)	42.940
Quantity of retail poultry, billion pounds (retail weight)	24.432
Quantity of wholesale poultry, billion pounds (carcass weight)	45.097
Quantity of wholesale poultry exports, billion pounds (carcass weight)	6.835
Price of retail poultry, cents per pound	178.000
Price of wholesale poultry, cents per pound	77.600

Notes: All quantity and price values reflect 2009 annual averages as obtained from the Livestock Marketing Information Center.