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RESEARCH ARTICLE

Farm Animal Welfare and Producer Profitability

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Abstract
Past research shows that farm animal welfare (FAW) policies can reduce consumer and retailer welfare, but producer welfare implications are less certain. This study uses equilibrium displacement modeling of the U.S. wholesale shell egg market to determine how the transition to cage-free egg sales could affect short- and long-run producer welfare. Under varying assumptions and retailer demand shifts, the results consistently demonstrate that producer profits are expected to decline as retailers pivot toward cage-free purchasing, holding all else constant. These findings help explain the tension surrounding FAW policies across the supply chain and can be used to inform industry and policymaker discussions on the topic.

Keywords: Cage-free eggs; equilibrium displacement model; farm animal welfare; welfare estimates

JEL classifications: Q11; Q13; Q18

1. Introduction

Several factors have driven the push toward enhanced farm animal welfare (FAW) production systems, including consumer demand (Clark et al., 2017; Lagerkvist and Hess, 2011), corporate social responsibility (Kapelko and Oude Lansink, 2022), and the burden of dealing with different regulations across jurisdictions (Staples et al., 2022). However, more stringent FAW systems are associated with higher fixed and variable production costs (Caputo et al., 2023; Lusk and Norwood, 2011; Matthews and Sumner, 2015), which could generate net welfare losses across the supply chain. Indeed, past research has explored this issue, often finding that state-level FAW production mandates reduce consumer and retailer welfare (Allender & Richards, 2010; Carter, Schaefer, and Scheitrum, 2021; Malone and Lusk, 2016; Mullally and Lusk, 2018; Oh & Vukina, 2022).

While these studies offer essential insights into the possible welfare implications of heightened FAW initiatives, a few gaps remain. First, past research has overlooked welfare implications earlier in the supply chain, failing to trace welfare effects back to the farm. Addressing this gap is critical as FAW initiatives could negatively affect producer welfare. The second gap stems from the past emphasis on state-level policy initiatives rather than voluntary retailer pledges. Though ten states have implemented policies or voluntary pledges to transition to cage-free egg production or sales (Hopkins, McKendree, and Schaefer, 2022), many of the largest U.S. retailers have voluntarily pledged to gradually transition to 100% cage-free sales in their stores (Lusk, 2019). Given the geographic scope of these retailers, the implications of voluntary pledges are widespread and will influence supply chain dynamics across the entire U.S. shell egg market.

This study uses an equilibrium displacement model (EDM) to explore the implications of retailer cage-free egg pledges on the U.S. egg market and producer profits. Following approaches outlined in Alston (1991) and Wohlgenant (2011), these issues are studied in the U.S. shell egg wholesale market context. Specifically, we consider a disaggregated egg market, where producers supply conventional and cage-free eggs to market, and their customers (i.e., retailers) choose between them. In our modeling efforts, the focus on this intermediate stage of the supply chain means that retailers represent demand and producers represent supply. The setting explores how retailer demand shifts away from conventional and toward cage-free eggs could affect egg producer profitability, holding all else constant.

Our contributions to the FAW economics literature stem from a series of thought experiments simulating the short- and long-run impacts of retailer FAW initiatives on producer profitability. We consider a constant expenditure setting in the U.S. wholesale shell egg market, where retailers shift purchasing away from conventional eggs and toward cage-free eggs while keeping total egg spending constant. Relatedly, we consider how much more (or less) retailers would have to spend to keep aggregate egg producers' profits constant while adjusting their conventional and cage-free purchasing rates. In previewing our results, the transition toward cage-free is consistently associated with declining producer profitability, where the magnitude of the estimate depends on model assumptions, parameter values, and the time horizon considered. The insights generated here help explain why tensions over FAW voluntary pledges remain and highlight why initial pledge deadline goals will not be met (Dawson, 2022).

2. Methodology

2.1. Equilibrium displacement model

Many studies have used EDMs to make *ex-ante* predictions about the effects of a policy or other exogenous shocks on market outcomes, including the U.S. egg industry (e.g., Keller, Boland, & Cakir, 2022; Sumner et al., 2010; Thompson et al., 2019). We use an EDM to model the disaggregated shell egg wholesale market, where retailers choose how many conventional and cage-free eggs to purchase at a given set of prices. The demand side of the model is defined as

$$\hat{Q}_C = \eta_{C,C}\hat{P}_C + \eta_{C,CF}\hat{P}_{CF} + \delta_C \tag{1}$$

$$\hat{Q}_{CF} = \eta_{CF,C}\hat{P}_C + \eta_{CF,CF}\hat{P}_{CF} + \delta_{CF} \tag{2}$$

where $\hat{P}_j$ is the proportionate change in egg price (i.e., $\hat{P} = \Delta P/P \approx \mathrm{dln}P/P$), $\hat{Q}_j$ is the proportionate change in demand or quantity demanded,[1] and $\eta_{j,k}$ are the price elasticities of demand. Subscript C represents conventional eggs, and CF represents cage-free eggs. Therefore, equation (1) is the change in demand or quantity demanded for conventional eggs, while equation (2) is the change in demand or quantity demanded for cage-free eggs. The own-price elasticities of demand for conventional ($\eta_{C,C}$) and cage-free ($\eta_{CF,CF}$) eggs are expected to be negative. Alternatively, cross-price elasticities are expected to be positive, where retailers likely consider conventional and cage-free eggs as substitutes ($\eta_{C,CF}>0$ and $\eta_{CF,C}>0$). Lastly, δ_j are demand shocks representing the proportional change in purchases; they are the magnitudes of the horizontal shift in the demand curve expressed relative to the initial equilibrium quantity.

[1]The quantity variable could represent a change in quantity demanded if the price of the good itself is altered, or it could represent a change in demand if the price of the substitute good or any other factor in δ changes. In this setting, we are primarily interested in modeling demand shifts and the resulting equilibrium changes. We thank an anonymous reviewer for raising this point.

The supply side of the model assumes independence in production,[2] where conventional egg supply does not depend on the price of cage-free eggs and vice versa. This is formally defined as

$$\hat{Q}_C = \varepsilon_C \hat{P}_C \tag{3}$$

$$\hat{Q}_{CF} = \varepsilon_{CF} \hat{P}_{CF} \tag{4}$$

where $\varepsilon_j > 0, j = \{C, CF\}$ are own-price elasticities of supply for conventional and cage free.

Equations (1) through (4) represent a system of four equations and four unknowns. Once elasticity values are assigned and demand shocks, δ_C and/or δ_{CF}, are assumed, we solve for the four endogenous variables representing changes in quantities and prices: $\hat{Q}_C$, $\hat{Q}_{CF}$, $\hat{P}_C$, $\hat{P}_{CF}$. Changes in total revenue/expenditure and egg producer profitability are then calculated using these values.

We use this framework to consider a simple thought experiment. For a given reduction in conventional egg demand ($-\delta_C$), how much would cage-free egg demand ($+\delta_{CF}$) have to rise to hold total egg expenditure constant? This *expenditure constant* calculation assumes retailers want to continue spending the same amount on eggs while adjusting their conventional and cage-free egg demand accordingly.[3] In this case, the levels of δ_C and δ_{CF} that force the following equality to hold is:

$$P_C^0 Q_C^0 + P_{CF}^0 Q_{CF}^0 = P_C^0(1 + \hat{P}_C)Q_C^0(1 + \hat{Q}_C) + P_{CF}^0(1 + \hat{P}_{CF})Q_{CF}^0(1 + \hat{Q}_{CF}). \tag{5}$$

Here, P_j^0 and Q_j^0 are the initial equilibrium price and quantity levels for egg type $j =$ conventional (C) or cage-free (CF). The left-hand side of equation (5) is the total expenditure on eggs in the initial equilibrium, while the right-hand side is the assumed total expenditure on eggs in the new equilibrium after the demand shocks.

While total retailer spending is held constant in this thought experiment, producer profitability need not be. In fact, the change in producer profitability (or producer surplus) in this framework is calculated as

$$\Delta\pi = \Sigma_{j=C,CF} P_j^0 Q_j^0 \hat{P}_j(1 + 0.5\hat{Q}_j). \tag{6}$$

Equation (6) shows that producer profits can fall even as retailers spend the same amount on eggs if the switch in demand results in more egg production from higher cost-of-production systems (Matthews and Sumner, 2015; Sumner et al., 2010).

Figure 1 shows the market effects of the offsetting demand shocks considered in this thought experiment. The left-hand side shows the market for conventional eggs, where the demand for conventional eggs by retailers is assumed to shift from D_C^0 to D_C^1. This moves the market from the equilibrium at point A to point B, as conventional egg prices and quantity produced fall. The right-hand side of the figure shows the offsetting effects in the cage-free market, where retailer demand for cage-free eggs shifts from D_{CF}^0 to D_{CF}^1. This moves the equilibrium from point C to point D as cage-free egg prices and quantity rise. The changes in conventional egg prices affect cage-free demand, creating a feedback loop between the markets, which the model accounts for through equations (1) and (2). Importantly, Figure 1 shows that the magnitude of the horizontal quantity demand shifts

[2]Assuming independence in production stems from the expectation that there would be limited cross-elasticity of supply in conventional and cage-free production, particularly in the short-run. The eggs are produced in different housing systems with different cost structures.

[3]The objective of our thought experiments is simply to demonstrate the dynamics behind the impact of FAW pledges on producer profitability given the uncertainty around the behavioral changes. The expenditure constant demand shift, as well as the other thought experiments considered in this study, may not perfectly depict the observed outcome of the transition. However, it demonstrates how changes exogenous shifts in producer supply or retailer demand can impact profitability. This is why we model a range of possible outcomes across different exercises. With consistent results (e.g., the direction of the sign for changes in producer profits), we believe that these provide valuable insights into the producer welfare implications of FAW policy. We discuss the limitations of the analysis more in the final section of the manuscript and thank anonymous reviewers for raising this point.

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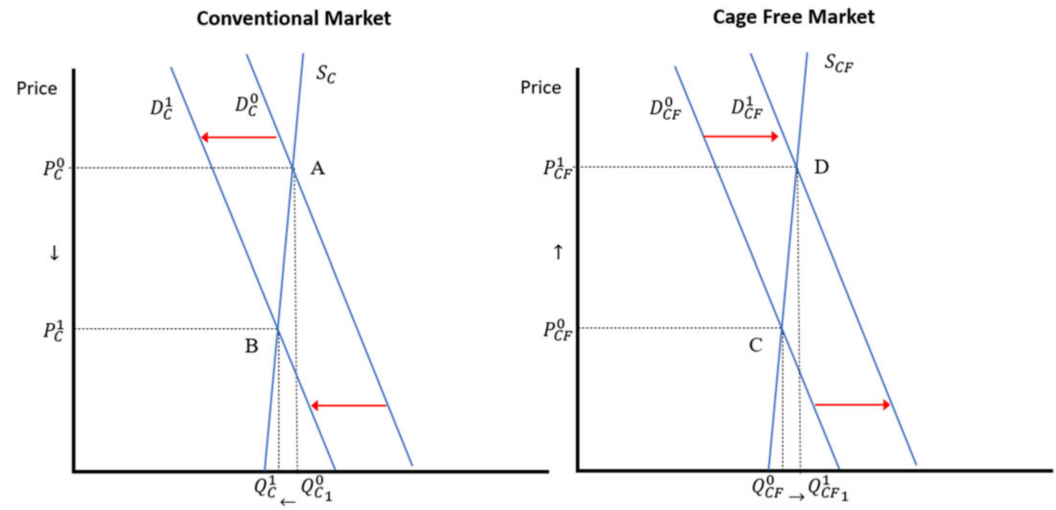

Figure 1. Effects of decrease in demand for conventional and increase in demand for cage-free.

(the red arrows, which represent δ_C and δ_{CF} in the model) are more prominent in absolute value than the equilibrium change in quantities. This is a result of the fact that δ_C and δ_{CF} measures how much more or less retailers are willing to buy *at constant prices*. However, as these shifts occur, prices change, which affects the quantity of eggs produced and purchased.

A second thought experiment is also considered within this framework. Rather than determining the magnitudes of the two demand shocks that hold retailer expenditures constant, it is possible to determine the magnitudes of the shocks required to hold producer profitability (equation (6)) unchanged. In this setting, the question becomes: How much would retailers have to spend on eggs to leave egg producers unharmed by the switch from conventional to cage-free egg demand?

2.2. Data and parameter estimation

Elasticities are estimated econometrically using monthly data from the USDA Agricultural Marketing Service (AMS) between January 2017 to September 2022 time period.[4] The January 2017 start date was chosen because it aligns with the USDA AMS release of its monthly Cage-Free Shell Egg Report. The data also contains information on wholesale contracts and negotiated loose cage-free egg prices, as well as data on cage-free and organic production. The reported cage-free contract price remains fixed for long periods, whereas the negotiated price is highly volatile; thus, for empirical analysis, we averaged the two wholesale prices for large eggs to represent the wholesale market price for cage-free eggs, as the reports do not contain information on quantities. We use the USDA AMS report data on cage-free and organic flock sizes and lay rates to calculate the monthly quantity of cage-free and organic eggs produced. The study uses the Urner Barry farm egg price conventional egg prices, as reported by the Iowa State Egg Industry Center (EIC).[5]

To determine conventional shell egg quantities, we use the quantity of table-type eggs produced as reported in the USDA National Agricultural Statistics Service (NASS) Chicken and Eggs monthly report.[6] This is an overestimate of the number of conventional shell eggs sold because it includes eggs that are ultimately broken, as well as cage-free and organic eggs produced. Thus, to

[4]The USDA AMS cage-free egg data are available at: https://usda.library.cornell.edu/concern/publications/rj4304553?locale=en [last accessed April 17, 2024].

[5]The Urner Barry data are available at: https://www.eggindustrycenter.org/industry-analysis [last accessed April 17, 2024].

[6]The USDA conventional egg data are available at: https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chickens_and_Eggs/index.php [last accessed April 17, 2024].

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calculate the quantity of conventional eggs sold in shell form in a given month, we take the total quantity of table-type eggs produced and subtract the reported number of eggs broken and the estimated number of cage-free and organic eggs produced.

Data on other control variables are used account for the economic and egg market volatility during the sampling period (e.g., Malone, Schaefer, and Lusk, 2021; Scheitrum, Schaefer, and Saitone, 2023). For example, employment rate data from the Bureau of Labor Statistics is used in the demand models to control for broader macroeconomic conditions, while the consumer price index deflates prices. For the supply models, we collected data on the cost of feed for egg production reported by the EIC and the number of egg-laying hens affected by avian influenza as reported by the USDA Animal Plant Health Inspection Service (APHIS). Table 1 presents a summary of the variables used in the analysis.

Given these data, demand elasticities are estimated using log-log regressions to directly interpret the estimated coefficients as elasticities. The basic structure of the demand models is as follows:

$$\log(Q_C) = \alpha_{o,C} + \beta_{C,C}\log\left(P_C/CPI\right) + \beta_{C,CF}\log\left(P_{CF}/CPI\right) + \gamma_{C,VID}COVID + \gamma_{C,EMP}\log(EMPLOY) + \sum_{m=1}^{11}\gamma_{C,m}Month_m + \epsilon_C$$

$$\log(Q_{CF}) = \alpha_{o,CF} + \beta_{CF,C}\log\left(P_C/CPI\right) + \beta_{CF,CF}\log\left(P_{CF}/CPI\right) + \gamma_{CF,VID}COVID + \gamma_{CF,EMP}\log(EMPLOY) + \sum_{m=1}^{11}\gamma_{CF,m}Month_m + \varepsilon_{CF}$$

where *CPI* is the consumer price index (normalized so that September 2022 is set to 1).[7] In this framework, $\beta_{i,j}$ are own-and cross-price elasticities of demand equal to $\eta_{j,k}$ in equations (1) and (2).

Table 2 shows the estimated coefficients. Elasticity estimates are of the expected sign and reasonable magnitude (e.g., Bakhtavoryan et al., 2021). The own-price elasticity of demand for conventional eggs is inelastic, where a 1% increase in the price of conventional eggs results in a 0.32% reduction in the quantity of conventional eggs demanded. Alternatively, cage-free egg demand is more elastic, where a 1% increase in cage-free egg prices is associated with a 1.07% decrease in the quantity of cage-free eggs demanded by retailers. Considering the cross-price elasticities, results suggest that conventional and cage-free eggs are demand substitutes. For example, a 1% increase in cage-free egg price is associated with a 0.31% increase in the quantity of conventional eggs demanded (statistically significant at the 10% level).[8]

Supply equations take a similar form, where we include supply-side shifters such as feed prices, an overall time trend to account for technological change, and the cumulative number of avian influenza cases in 2022. The model also includes a one-period lagged value of the dependent variable to account for asset fixity and partial adjustment to price changes.

Table 3 presents the supply elasticities for conventional and cage-free eggs, suggesting that both are highly inelastic. Accounting for the lagged dependent variable, the conventional egg elasticity is 0.2, implying that a 1% increase in conventional egg price is associated with a 0.2% increase in the quantity of conventional eggs supplied. Likewise, the short-run supply elasticities for cage-free eggs is 0.32. The estimated price elasticities are substituted into equations (1) through (4) to determine the effects of demand shifts.

[7]Demand models are homothetic of degree zero in prices.

[8]Demonstrating the impact of economic conditions, COVID (the period from March to June 2020) is associated with a 27.1% increase in conventional shell egg demand and a 40.5% reduction in cage-free demand (statistically insignificant).

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Table 1. Descriptive statistics for variables used in regression analysis

Variable	Source	Units	Mean	Minimum	Maximum
Conventional Egg Price (P_C)	Urner Barry farm price	\$/dozen	0.917	0.231	2.710
Cage-free Egg Price (P_{CF})	USDA AMS Cage-free Shell Egg Report; Average of contract and negotiated prices	\$/dozen	1.462	0.287	1.085
Conventional Egg Quantity (Q_C)	Calculated from data in the USDA NASS Chicken & Egg Report and USDA AMS Cage-Free Shell Egg Report	million eggs	3910.98	2365.36	4719.70
Cage-free Egg Quantity (Q_{CF})	Calculated using data from USDA AMS Cage-free Shell Egg Report; does not include organic	million eggs	1325.08	512.40	2425.34
Employment Rate	Bureau of Labor Statistics; Percent of the population employed	%	60.7%	52.6%	62.7%
COVID	Calculated; equals 1 for March through June 2020; 0 otherwise	0,1	0.058	0	1
Cost of Feed	Iowa Egg Industry Center; Regional Average	\$/lb	0.115	0.092	0.168
Avian Influenza	USDA APHIS; the cumulative number of hens affected in 2022	million hens	3.06	0.00	36.70

Table 2. Estimates of demand for conventional and cage-free eggs

	Coef. (std. error)	
Parameter	**Conventional egg demand** log (Q_C)	**Cage-free egg demand** log (Q_{CF})
Conventional Egg Price, log (P_C)	−0.321*** (0.057)	0.682*** (0.149)
Cage-free Egg Price, log (P_{CF})	0.307* (0.176)	−1.065*** (0.455)
Log of Employment Rate	1.374** (0.661)	−5.560*** (1.708)
COVID	0.274*** (0.097)	−0.405* (0.250)
Constant	2.520 (2.709)	30.590*** (7.002)
N	**69**	**69**
Month fixed effects	Yes	Yes
R^2	0.538	0.420

Notes: Superscripts ***, **, and * denote statistical significance at the one, five, and ten percent levels, respectively. Model estimates the full table with month fixed effects estimates is available in the Appendix (Table A1).

We interpret these estimates as short-run supply elasticities, which assess the immediate implications of the transition toward cage-free. While short-term impacts are insightful, long-run implications must also be considered.

2.3. Assessing long-term adjustments

The effects of transitioning toward retailer cage-free pledges are not isolated to one year. Thus, we consider an extended timeline considering (i) gradual demand shocks away from conventional

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Table 3. Estimates of supply for conventional and cage-free eggs

	Coef. (std. error)	
Variable	**Conventional Egg Supply** log (Q_C)	**Cage-free Egg Supply** log (Q_{CF})
Conventional Egg Price, log (P_C)	0.015 (0.012)	—
Cage-free Egg Price, log (P_{CF})	—	0.098** (0.045)
Log Feed Price	−0.076 (0.055)	−0.062 (0.054)
Cumulative Bird Flu Cases	−0.000 (0.001)	−0.002** (0.001)
log ($Q_{C,t-1}$)	0.924*** (0.096)	—
log ($Q_{CF,t-1}$)	—	0.695*** (0.084)
Constant	0.496 (0.754)	1.831*** (0.504)
N	**69**	**69**
Month fixed effects	Yes	Yes
Time trend	Yes	Yes
R^2	0.976	0.993

Notes: Superscripts ***, **, and * denote statistical significance at the one, five, and ten percent levels, respectively. The full table with month fixed effects and a time trend are available in the Appendix (Table A2).

eggs and (ii) adjustments toward long-run elasticity values based on insights from the literature. The idea of a long-term adjustment and extended timeline is commonly seen in empirical studies using EDMs (e.g., Schroeder and Tonsor, 2011; Weaber and Lusk, 2010).

Our framework assumes a 10-year window with conventional egg demand shocks ranging from −5% in year 1 to −15% by year 5. Over this 10-year window, the conventional and cage-free supply curve elasticities are assumed to linearly adjust from the estimated short-run values (Table 3) to an assumed long-run value of 0.94, following insights by Bakhtavoryan et al. (2021). This adjustment toward more elastic supply curves would be expected as producers build cage-free facilities, hire more specialized labor, etc. To test the sensitivity of our estimates, we also consider a second case where the supply curve is twice as elastic.

These procedures allow us to assess annual impacts under different conventional demand shocks and supply elasticity estimates. We start in year 1 and assume that the elasticity of supply for each egg type presented above: 0.19 for conventional and 0.32 for cage-free. We then run the EDM assuming a conventional egg demand shock of −5% and compute the annual impact the shock has on key metrics: the expected change in producer profitability and the necessary change in retailer spending to keep producer profits constant. In year 2, the conventional and cage-free supply elasticities become more elastic, linearly adjusting to long-term values.[9] We assume the shift away from conventional continues, increasing the conventional shock to −7.5%. New annual impacts are estimated for year 2 by rerunning the EDM with these values. We continue to adjust

[9]For example, assuming that the long-term elasticity of supply for both conventional and cage-free is 0.94, the elasticity of supply for conventional becomes 0.38 in year 2, whereas the elasticity of supply for cage-free becomes 0.50.

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the conventional shock (until it reaches a −15% shock in year 5) and supply elasticities toward the long-run assumed value (Bakhtavoryan et al., 2021). By iterating the model over the full adjustment period and calculating expected annual impacts from the transition, we estimate the net present value (NPV) using a 5% discount rate in each thought experiment to capture the potential longer-run impacts.[10]

The model was initiated using 2021 conventional and cage-free prices and quantities. While the voluntary pledges were supposed to go into effect by 2025, retailers announced delays in meeting pledge deadlines. Some retailers have set new target dates to hit partial adjustment milestones (e.g., Kroger aims to reach 70% cage-free by 2030; Dawson, 2022), while others only state they will continue their transition with no public pledge deadlines (Dawson, 2022). Thus, we believe an incomplete transition and a ten-year time horizon is an appropriate approach for this exploratory analysis.

3. Results of disaggregated egg market analysis

3.1. Expenditure neutral demand shifts

The first thought experiment considers a situation where retailers wish to hold total egg purchase expenditures constant, in dollar terms, while transitioning from conventional to cage-free. Figure 2 shows the offsetting demand shifts and resulting equilibrium quantities that would produce this expenditure-neutral outcome in the short run.

Panel A of Figure 2 shows that for every 1% reduction in conventional egg demand, a roughly 2.5% increase in cage-free egg demand is required to hold total egg spending constant. For example, if conventional egg demand falls by 5%, cage-free egg demand must increase by 12.7% to keep total spending constant. However, as demand shifts are larger than the changes in ultimate equilibrium quantities, Panel B of Figure 2 shows the same outcomes in equilibrium quantity changes. Here, a 1% reduction in the equilibrium quantity of conventional eggs produced and sold requires a 1.7% increase in the equilibrium quantity of cage-free eggs produced and sold to hold total expenditures/revenue constant. The base quantity differences reflect the prevalence of conventional eggs such that it takes a larger percentage adjustment in cage-free systems to equate a smaller percentage but similar magnitude changes in conventional systems.[11]

We then use total 2021 prices and production to set the initial equilibrium expenditure/revenue and calculate the impact of these revenue-neutral demand shifts on egg producers. Using the short-run elasticity estimates, Figure 3 shows that these expenditure-neutral changes are expected to decrease egg producer surplus. For example, if retailer demand for conventional eggs falls by 5% while cage-free egg demand increases by 12.7%, egg producers' profits will fall by $18.7 million despite retailers keeping their egg expenditures constant.

Table 4 considers the long-run impact of the transition in NPV terms across two cases where supply linearly adjusts to long-run estimates over a 10-year period. Case 1 borrows the long-run supply elasticity of 0.94 presented in Bakhtavoryan et al. (2021), while Case 2 considers a more elastic long-run supply curve of 1.88 (i.e., double the elasticity presented in case 1). Both cases assume that the elasticity of supply linearly adjusts over the 10-year project timeline. The assumed exogenous shock in year 1 is 5%, and the model increases by 2.5% each year until year five, when it reaches a 15% shock away from conventional. After year 5, the shock remains consistent at 15%, as EDMs are best when considering marginal changes (Wohlgenant, 2011). While retailers will likely continue shifting toward cage-free to meet their pledge goals (representing a larger shock to the conventional market), the output here can be considered a more conservative shift.

[10]We also consider the sensitivity of our NPV estimates to different discount rates (Table A4).

[11]Mean values in Table 1 reflect cage-free volume being 25% of the total market and cage-free representing 35% of system revenues. Accordingly, it takes larger percentage changes in the smaller, cage-free segment to offset changes in the conventional segment.

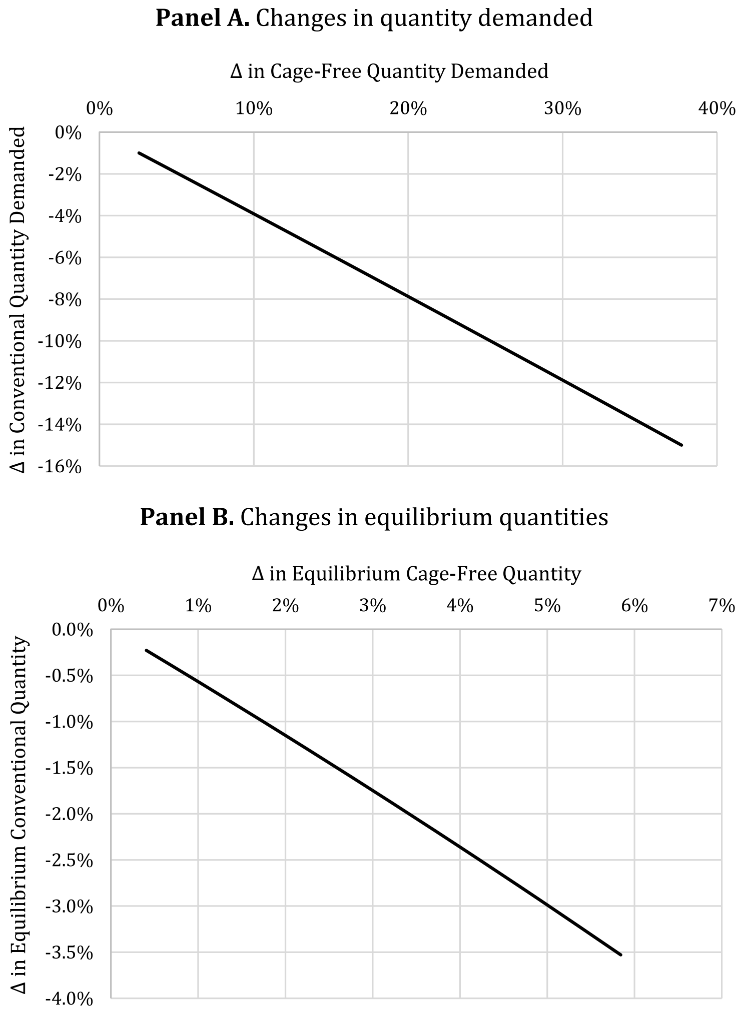

Figure 2. Expenditure-neutral shifts in conventional and cage-free egg demand.

The long-run results are consistent with short-run expectations, where the transition toward cage-free is associated with a net reduction in producer welfare. Considering the 10-year timeline and discount rate of 5%, the model predicts a NPV reduction in producer profits of \$64.9–\$130.6 million.[12] In raw dollar terms, the reduction in producer profits is greatest in year four in Case 1 and year two in Case 2. Additionally, the reduction in producer surplus approaches zero further out in time, becoming positive in year 8 in Case 2. This could suggest that the net effects (i) are smaller under more elastic long-run supply curves and (ii) could diminish over time when holding the magnitude of the shock constant each year. However, the immediate reductions in expected

[12]Table A4 presents the key NPV measures from Table 4 under different discount rates to test the sensitivity of these results. Discount rates used in this additional analysis range from 0.025 to 0.10. Under the assumption that the supply curve adjusts to a long-run elasticity of 0.94, the change in producer surplus from the revenue value equivalent case ranges from a NPV of −\$144.0 million (discount rate = 0.025) to −\$109.0 million (discount rate = 0.10). The producer profit equivalent case requires a NPV change in spending ranging from \$160.4 million (discount rate = 0.10) to \$214.2 million (discount rate = 0.025) to keep producer profits unharmed. If we assume the long-run elasticity of supply is 1.88, estimates range from −\$68.0 million to −\$58.8 million in the revenue value equivalent case and \$87.9 million to \$99.5 million in the producer profit equivalent case.

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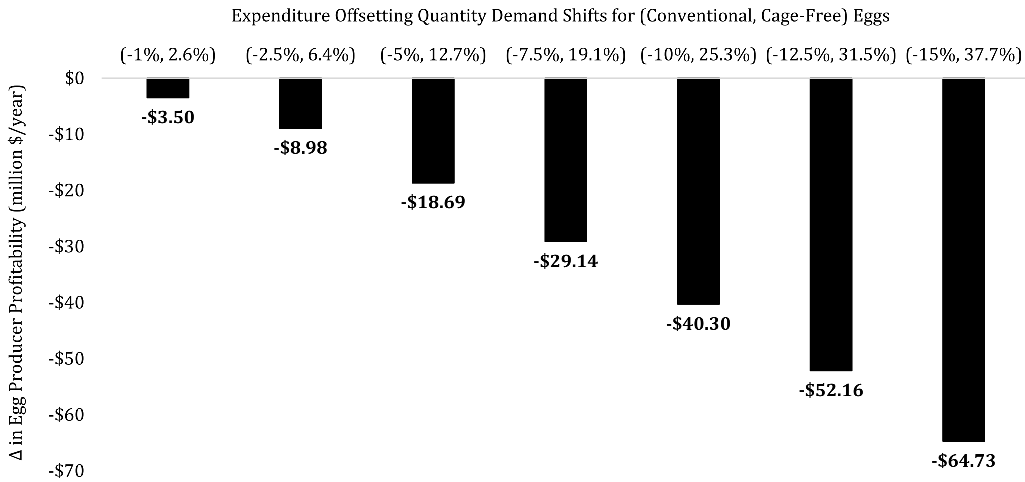

Figure 3. Impacts of expenditure-neutral demand shifts on egg producer profitability.

profitability and negative NPV estimates over 10 years could explain why producers are hesitant to adopt cage-free systems.

3.2. Egg producer profit neutral demand shifts

Instead of determining the corresponding demand shifts that result in the same total egg spending by retailers, we now explore how much cage-free egg demand would have to rise to leave producers' profits unharmed.[13]

Short-run estimates suggest that for every 1% reduction in conventional egg demand, a roughly 2.6% increase in cage-free egg demand is required to hold producer profit constant. For example, if conventional egg demand falls by 5%, cage-free egg demand must increase by 13.2% to hold egg producer profits at their initial levels. As indicated previously, demand shifts are larger than the changes in ultimate equilibrium quantities. For every 1% reduction in the equilibrium quantity of conventional eggs produced and sold, it takes a roughly 1.9% increase in the equilibrium quantity of cage-free eggs produced and sold to hold total egg producer profits constant.

As is likely apparent from this discussion, retailers will have to spend more on eggs to hold egg producers unharmed as they shift from conventional to cage-free eggs. Figure 4 shows how much more retailers would have to spend on eggs (in total) to leave short-run producer profitability unharmed as they shift from conventional to cage-free eggs. For example, if conventional egg demand falls by 5%, retailers would have to increase cage-free demand by 13.2% and spend $23.8 million more on eggs to leave producer profitability unchanged. In market equilibrium quantity terms (rather than in terms of demand shifts), if the quantity of conventional eggs produced and sold falls by 1.1%, retailers would have to increase the quantity of cage-free eggs purchased by 2.15% (spending $23.8 million more on eggs) to leave producer profitability unchanged.

The long-run impact analyzes an an identical setup as the previous thought experiment under an extended timeline (Table 4). Case 1 assumes the long-run conventional and cage-free supply elasticities are 0.94, while Case 2 assumes they are 1.88. The results indicate that retailers would have to spend $95.8–$193.6 million more in NPV terms over the ten years to hold producer profits constant. In raw dollar terms, the greatest change in retailer spending would be required in year 5

[13]While we quantify effects that would leave producer profits ($) unchanged given elevated production costs, producers may experience different returns-on-investment or value autonomy such that they sustain a preference for conventional even if profits ($) are unchanged. Future research could explore this relationship.

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Table 4. Long-run estimates in the disaggregated egg market regarding the impact of the transition on producer welfare

Year	1	2	3	4	5	6	7	8	9	10
Assumed conventional shock	−5.0%	−7.5%	−10.0%	−12.5%	−15.0%	−15.0%	−15.0%	−15.0%	−15.0%	−15.0%
Case 1. Long-run elasticity of supply = 0.94										
Conventional supply elasticity	0.192	0.275	0.358	0.441	0.524	0.608	0.691	0.774	0.857	0.940
Cage-free supply elasticity	0.322	0.391	0.459	0.528	0.597	0.665	0.734	0.803	0.871	0.940
Revenue value equivalent										
Shock cage-free	12.7%	18.0%	22.7%	26.9%	30.8%	29.7%	28.8%	28.0%	27.4%	26.7%
ΔQ conventional	−1.2%	−2.3%	−3.6%	−5.1%	−6.8%	−7.3%	−7.8%	−8.2%	−8.6%	−8.9%
ΔQ cage-free	2.0%	3.3%	4.8%	6.3%	7.9%	8.3%	8.6%	8.9%	9.4%	9.5%
Annual ΔPS (millions)	−$18.7	−$22.8	−$24.6	−$25.9	−$23.9	−$17.3	−$12.1	−$7.7	−$6.7	−$0.8
NPV ΔPS (millions)					**−$130.6**					
Producer profit equivalent										
Shock cage-free	13.2%	18.6%	23.4%	27.8%	31.8%	30.5%	29.4%	28.4%	27.5%	26.7%
ΔQ conventional	−1.1%	−2.2%	−3.5%	−5.0%	−6.7%	−7.2%	−7.7%	−8.1%	−8.5%	−8.9%
ΔQ cage-free	2.1%	3.5%	5.1%	6.6%	8.3%	8.6%	8.9%	9.1%	9.3%	9.5%
Annual Δ spending (millions)	$23.8	$30.9	$35.4	$37.8	$38.0	$28.7	$21.0	$14.0	$7.3	$1.5
NPV Δ spending (millions)					**$193.6**					
Case 2. Long-run elasticity of supply = 1.88										
Conventional supply elasticity	0.192	0.380	0.567	0.755	0.942	1.130	1.317	1.505	1.692	1.880
Cage-free supply elasticity	0.322	0.495	0.668	0.841	1.014	1.188	1.361	1.534	1.707	1.880
Revenue value equivalent										
Shock cage-free	12.7%	16.9%	20.6%	23.8%	26.9%	25.7%	24.8%	24.1%	23.5%	23.0%
ΔQ conventional	−1.2%	−2.8%	−4.7%	−6.8%	−8.9%	−9.6%	−10.1%	−10.5%	−10.8%	−11.1%
ΔQ cage-free	2.0%	3.8%	5.7%	7.8%	9.9%	10.5%	11.0%	11.4%	11.8%	12.1%

(*Continued*)

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Table 4. (*Continued*)

Year	1	2	3	4	5	6	7	8	9	10
Annual ΔPS (millions)	−$18.7	−$18.8	−$17.1	−$13.9	−$9.8	−$4.5	−$0.8	$2.1	$4.3	$5.9
NPV ΔPS (millions)					**−$64.9**					
Producer profit equivalent										
Shock cage-free	13.2%	17.6%	21.3%	24.5%	27.4%	26.0%	24.9%	23.9%	23.1%	22.4%
ΔQ conventional	−1.1%	−2.7%	−4.6%	−6.7%	−8.9%	−9.5%	−10.1%	−10.5%	10.9%	−11.2%
ΔQ cage-free	2.1%	4.0%	6.1%	8.1%	10.2%	10.7%	11.0%	11.3%	11.5%	11.7%
Annual Δ spending (millions)	$23.8	$27.6	$28.2	$25.3	$19.6	$9.9	$1.8	-$5.3	-$11.3	-$16.6
NPV Δ spending (millions)					**$95.8**					

Note: The net present value (NPV) calculation uses a discount rate of 0.05.

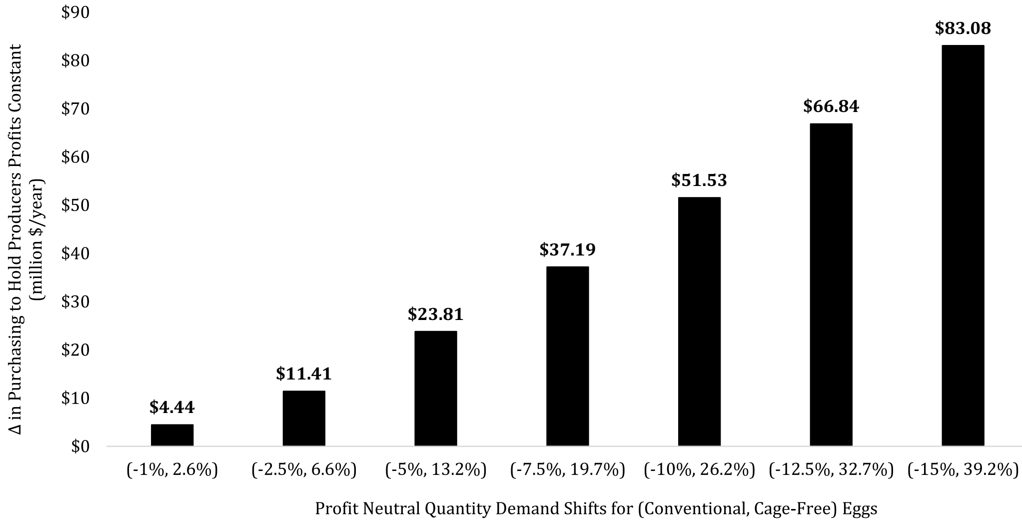

Figure 4. Increases in retailer egg spending required to hold egg producers' profits constant.

in Case 1 but year 3 in Case 2. The additional expenditure required to hold profits constant approaches zero as time passes, eventually flipping signs in year 8 of Case 2. Thus, much like the expenditure-constant setting, the yearly welfare losses are predicted to be greatest in the short run and diminish as supply adjusts to long-run values.

4. Discussion and conclusion

Imposing stricter FAW policies has non-trivial costs on stakeholders across protein supply chains (Carter et al., 2021; Malone and Lusk, 2016; Matthews and Sumner, 2015; Mullally and Lusk, 2018; Oh & Vukina, 2022; Sumner et al., 2011). As some states and many large U.S. retailers impose mandates or voluntary pledges to transition to 100% cage-free egg sales, it is important to evaluate the potential welfare effects for key stakeholder groups. This study uses an EDM and series of thought experiments to evaluate the short- and long-run impacts of cage-free shifts on producer welfare in the wholesale shell egg market.

The primary takeaway from our modeling efforts is that producer surplus is expected to fall as retailers pivot toward cage-free purchasing. The study models a disaggregated egg market where conventional egg demand decreases and cage-free demand increases. Across two thought experiments where we vary model assumptions, parameter estimates, and time horizons, the results consistently demonstrate an expected decline in producer welfare. For example, long-run estimates in one thought experiment demonstrate that producer profits are expected to fall between $65 and $131 million in NPV terms over a 10-year period. Most of the negative impacts are felt in the short- and intermediate-term as supply adjusts from short- to long-run elasticities, and more elastic supply curves are generally associated with a smaller reduction in producer welfare.

Overall, the magnitude of these estimates seems reasonable but are smaller than past studies suggesting potential consumer and retailer welfare reductions from enhanced FAW policy (Carter et al., 2021; Malone and Lusk, 2016; Mullally and Lusk, 2018; Oh & Vukina, 2022). For example, Oh & Vukina (2022) focus on California's complete conversion to cage-free, showing an annual expected welfare reduction of $72 million and $23 million for in-state consumers and retailers, respectively. Carter et al. (2021) assess California's policy mandating that all eggs sold in the state come from eggs housed in cage-free or enlarged caged facilities. They find that the policy resulted in a total decrease in national consumer and producer welfare of more than $2.6 billion from 2015 to 2017. As our study only assesses a partial shift toward an FAW initiative, the smaller value observed here is unsurprising.

Assessing the magnitude of our estimates on current egg producer profits is more difficult as this information is not widely available. Producer profitability depends on several factors, including firm size, current production techniques, input costs, and other market conditions. Without specific data on profit margins, determining whether the anticipated short- and long-term reduction in expected profitability is trivial or substantial remains less certain. Nonetheless, the results help explain why producers may hesitate to adjust production toward cage-free without known incentives.

Our study extends the FAW economics literature in two ways. First, we focus on farmer welfare implications, focusing on the wholesale shell egg market and changes in producer profitability. Second, we emphasize voluntary retailer pledges instead of state-imposed mandates. The strength of EDMs is assessing incremental changes rather than complete shifts (Wohlgenant, 2011). Hence, our emphasis on the wholesale market is purposeful and symbolic of the voluntary retailer pledges of gradually transitioning to 100% cage-free sales.

The study also has several potential policy and marketing implications. First, it stresses the supply chain dynamics, capital commitments, and timeline for cage-free adoption. Retailers cannot immediately switch from current purchasing patterns to 100% cage-free at will, as producers will wait to expand cage-free facilities until they have a buyer (Caputo et al., 2023). Thus, retailers will need to incrementally increase cage-free egg purchasing leading up to pledge deadline goals. Of course, this then introduces a challenge for the retailer, given that consumers may prefer purchasing the conventional egg despite expressing support for the pledge (Norwood, Tonsor, and Lusk, 2019; Paul et al., 2019). Modeling this dynamic retailer-producer relationship and the expected welfare outcomes helps explain why the transition period has been a point of tension in the industry. In fact, the anticipated decline in producer profitability – particularly at the onset of the transition when supply curves are highly inelastic – could explain why initial retailer pledge deadlines will not be met (Dawson, 2022).

A second area of policy consideration is the implications of this transition on small versus large producers. The expected decline in producer profits modeled here is unlikely to be evenly distributed across all producers due to economies of scale, access to capital, etc. Indeed, several producers interviewed in Caputo et al. (2023) expressed concern that the cage-free transition would be more challenging for smaller producers and could drive industry consolidation. We cannot disentangle these effects across small and large producers using our aggregated approach (i.e., we do not observe firm-level production). However, this is an area for future research, given the heightened policy attention on competition in animal protein markets (e.g., Executive Order 14036).

While the strength of assessing incremental supply and demand shifts is highlighted through the EDM, the study is not without limitations. Primarily, this study explores the isolated shocks associated with converting from conventional to cage-free housing. We recognize that future observed market changes could be muted or amplified as other demand- or supply-side shocks (e.g., changes in feed prices, income levels, avian influenza) invariably hit the system. However, modeling and interpreting the effects of multiple shocks becomes increasingly complex and sensitive. Secondly, our study focuses exclusively on the wholesale shell egg market between producers and retailers. The exclusive focus on the shell egg market is not a major concern, as the shell egg market has transitioned toward cage-free faster than the liquid egg marketplace (Lusk, 2019).[14] However, future work could consider the downstream relationship between retailers and the end consumers. Additionally, future research should consider the pass-through rate of the

[14]One potential explanation for this distinction between shell and breaker egg marketplaces is the salience of a cage-free label on an egg carton rather than as an ingredient on a processed food box or in a food service setting (Caputo et al., 2023).

increase in production costs down the supply chain to the end consumer (Sumner, 2018) and potential heterogeneous supply and demand responses to FAW initiatives across regions.

Despite these limitations and areas for future work, our results offer novel insights into the implications of FAW initiatives on producer welfare. Specifically, we convey the dynamics of the retailer-producer relationship and demonstrate the basic economic reasons behind ongoing tension across the supply chain regarding the transition to cage-free.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/aae.2024.40.

Data availability statement. The data are available upon reasonable request.

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AI declaration. None.

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