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Increasing the federal minimum wage is a major issue in the 2020 presidential campaign**.** This paper's objective is to evaluate the impact of an increase in the minimum wage on an industry, eggs, where labor is a key input. This analysis was carried out using an equilibrium displacement model. When spread across the industry, the total negative effects due to increasing the minimum wage does not appear to be economically significant. This is due in large part to the Iowa egg industry's current equilibrium wage of $13.50 an hour. Consequently, imposing a $15.00 an hour minimum wage would be a difference of only $1.50 assuming the egg industry does not increase it further. However, to stay competitive, egg industry employers would likely need to increase its wage to some level above $15.00 should the minimum wage be increased to that level. Despite these seemingly small effects, egg producers may nonetheless struggle in the short run to respond to immediate labor expenses should the state (or nation) not phase in its minimum wage over the course of several years. Most likely, if Iowa were to increase its minimum wage to $15.00 an hour, it would follow the lead of other states and incrementally increase its minimum wage over the course of many years until reaching $15.00.

JEL Codes: J38, J43, Q12, Q13

Key words: agriculture, eggs, equilibrium displacement models, labor, minimum wage

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The Impact of an Increase in the Federal Minimum Wage on the Egg Industry

Increasing the federal minimum wage is a major issue in the 2020 presidential campaign and was the first item on the 2016 Democratic Party Platform. In July 2019, the U.S. House of Representatives passed a bill to set the new federal minimum wage at $15.00 an hour—an increase of $7.75. This bill, however, did not make it out of the Senate. Since the Fair Labor Standards Act of 1938 (FLSA)'s inception, the average minimum wage increase has been 17.5%. A $15 minimum wage would entail a 106% increase. A hypothetical, immediate national 100% wage hike could strongly disrupt any labor-intensive industry, especially in agriculture and, more specifically, in industries where labor is an important input, such as animal agriculture. This article's objective is to evaluate the impact of an increase in the minimum wage on an industry, eggs, where labor is a key input.

Overview of Federal and State Policies on Minimum Wages

In recent years, increases to the minimum wage and other aspects of overall wage, including health insurance and retirement contributions, have been widely debated. Congress introduced the first successful federal minimum wage by passing the FLSA. The FLSA established that all workers involved in the production of goods for interstate commerce—commerce between and among different states—were to be paid no less than 25 cents an hour. The minimum wage does not rise with inflation, so it can only change through an act of Congress. Congress has raised the minimum wage 22 times, with the average gap between increases being about three years. In 2020, the hourly wage set by the more than decade-old Fair Minimum Wage Act of 2007 has not changed, and the U.S. maintains a federal minimum wage of $7.25.

A slight majority of states currently have minimum wages that exceed the federal minimum wage. Figure 1 shows the minimum wages for each state beginning January 1, 2021. Several states have passed legislation for a $15 minimum wage and are incrementally increasing the wage over multiple years until that target wage is reached. It is likely that if a significant increase to the federal minimum wage is passed, Congress will phase the increase in over the course of several years. Figure 2 shows egg production by state. A comparison of figures 1 and 2 shows that most of the major egg-producing states currently have a relatively low minimum wage. This suggests that a new federal minimum wage could be especially impactful to the egg industry. Many individual states will probably continue to increase their minimum wages periodically. This research looks specifically at Iowa, the nation's leading egg producer that currently has a minimum wage of $7.25, because if there is an impact, it is likely to be seen in a state with a large egg industry and a low minimum wage.

Note to technical editor: please place figures 1 and 2 about here

The Iowa Egg Industry

Iowa is the leading egg-producing state in the United States.[1] The state's abundance of feedstocks (corn and soybean meal) makes it an ideal place for egg production, as feed makes up about 50% of total production costs (Ibarburu, Schulz, and Imerman 2019). This gives Iowa a competitive advantage over other states. On the other hand, Iowa lacks proximity to major population centers and therefore faces higher transportation costs when bringing eggs to market. As a result, Iowa processes (i.e., "breaks") a higher percentage (about 70% total) of eggs than producers in states closer to large population centers (Ibarburu, Schulz, and Imerman 2019). Specifically, Iowa's broken eggs are less costly to transport than are shell ("table") eggs.

In 2018, the industry marketed $1.333 billion of eggs and added 2,398 direct jobs and 7,084 total jobs via the value-added process in Iowa (Ibarburu, Schulz, and Imerman 2019). The egg industry also generated $450 million for egg worker salaries within the state, with the average salary rising to $45,967 per worker from $37,259 in 2014. Given the importance of labor in egg production, wages must be at an adequate level to maintain a steady supply of productive workers.

Wages in Iowa's Egg Industry

Comprehensive data on entry-level egg industry wages are not publicly available. The U.S. Bureau of Labor Statistics (BLS) does, however, publish a *Quarterly Census of Employment and Wages,* which provides average weekly wages for the egg industry in many U.S. counties. Unfortunately, the data is aggregated in such a way that prevents one from accurately extrapolating hourly wages for egg facility laborers. Another data source is online job postings. In March 2020, of the nearly 60 Iowa egg industry entry-level listings on *www.indeed.com*, seven had stated an hourly wage. The average wage of those seven listings was $13.50 an hour with benefits.

Iowa egg industry employers face a disadvantage in relation to the employers of similarly skilled positions in more-urban areas. Egg laborer positions are generally less desirable than cleaner, less labor-intensive, and more urban entry-level positions such as those in retail and fast food. Consequently, the egg industry competes by offering higher wages and good benefits. In the event of a minimum wage increase, these compensation advantages would need to be maintained by egg industry employers to keep enough workers at their facilities. To put this into perspective, one alternative to working at an egg facility would be the foodservice industry. The

BLS statistics for the mean hourly wage for the "Food Preparation and Serving Related" category in Des Moines, Iowa, in May 2018 was $11.82 (U.S. Bureau of Labor Statistics 2018). The wages for egg industry positions are set significantly higher than food preparation jobs in Des Moines to attract and maintain a large enough workforce. With a current minimum wage in Iowa of $7.25, the food service workers in Des Moines earn 63% above the minimum wage. Egg workers make 86% above the minimum wage and 14% more than food service workers. Keeping wages above those of competitors is a necessity in the egg industry to draw workers into rural Iowa where there is a lack of suitable housing and other amenities.

Previous Economic Research on the U.S. Egg Industry

In recent years, two major topics have defined the literature on egg industry economics. One is the transition toward cage-free systems, as reviewed in Malone and Lusk (2016) and Mullally and Lusk (2017). The second is the impact of avian flu outbreaks on producers and consumers (Sumner et al. 2010, Çakır, Boland, and Wang 2018, Thompson et al. 2019). Labor-dependent industries, including perennial crop producers and animal agriculture, are exploring ways to substitute technology for manual labor. However, the nature of egg production is already highly automated such that the use of potential technology to further substitute for manual labor is not a realistic possibility in the near future. Iowa producers benefit from a relatively low minimum wage, such that egg industry labor costs in Iowa make up a lower percentage of total costs than those of other states. An increase in Iowa's minimum wage could erode this advantage.

Equilibrium Displacement Models

An Equilibrium Displacement Model (EDM) is chosen to analyze the effect of an increase in the minimum wage on Iowa's egg industry. What separates EDMs from a simple budget analysis is their ability to consider entire systems and their equilibrium effects, which was first noted by Muth (1965). These EDM models have been frequently used to analyze the impacts of policy. Gardner (1975) is a significant contribution to the EDM literature. Gardner uses a six-equation system to derive reduced-form equations. The exogenous shifters within these reduced-form equations are then used to examine their effects on retail/farm price ratios.

In May 2020, AgEcon Search, the world's largest depository for published research on agricultural economics, had 118 manuscripts using this type of model. The EDMs are valued for their flexibility, as they can address both supply and demand phenomena. From the modeler's perspective, one benefit to using an EDM is the ability to forgo the data collection and estimation needed to derive supply and demand equations; that is, elasticities can be taken from existing literature on the topic. However, because the true underlying functional form of the desired industry is almost certainly non-linear, the EDM will produce distorted results in a direction that depends on the shape and level of the true functional form. The results of EDMs improve on the insights that can be seen using graphical analysis, such as in Figure 3.

The Effects of a Supply-Side Shock

Figure 3 shows the impact of a supply shock along the vertical egg supply chain. Beginning with an arbitrary shock to labor costs, each level's supply curve, S, shifts inward to S', causing an increase in price, p, and a decrease in quantity, x. As the farm level (the breeder, denoted by subscript f in Figure 3) incurs its added labor costs, subsequent contracts for the sale of its chicks will demand a higher price from the wholesaler egg producer, denoted by subscript w. Consequently, the wholesaler incurs a secondary supply shock, S'', when purchasing its replacement pullets. The labor shock also affects the retailer denoted by the subscript, r, in Figure 3. First, as mentioned, the retailer incurs added labor costs due to all increased wages from the new minimum wage. This shifts the supply curve inward. Second, the retailer must now purchase eggs from the wholesaler at a higher cost due to the shift in wholesaler's supply. The retailer responds by increasing the retail price of eggs, which causes the primary demand to fall. The wholesaler then experiences an endogenous inward shift in the derived demand for eggs from D to D'. Figure 3 demonstrates that an inward shift of the labor supply causes prices to increase and quantities to fall. Note, however, that this figure is based on a shift in the supply curve, as opposed to a wedge. A wedge in prices and quantities usually occurs from government intervention, often from the implementation of a price floor or ceiling (Just, Hueth, and Schmitz 2004). Wedges in labor quantities and prices, for example, can be caused by the implementation of a minimum wage—a type of price floor. The distinction between shifts and wedges is important and leads to the use of different versions of the model.

Many previous EDMs begin with the consideration of only the relevant supply and demand equations (e.g., Lusk and Anderson 2004). From there, parameters are chosen, and the system of supply and demand equations are solved with the assistance of matrix algebra. Unlike other agricultural EDM models for meats such as beef, pork, and poultry, and their interactions with each other, this EDM model omits a horizontal component and does not look at inter-industry interactions. This is because there is currently no significant substitute for eggs. Although some plant-based substitutes are currently being introduced, their market share is small or non-existent relative to plant-based meat or milk in 2020. One such example is JUST Egg, a vegan egg alternative. At the close of 2019, its makers, JUST Inc., greatly expanded its operations with the goal of producing its vegan eggs at a per-unit price lower than that of traditional eggs. However, its production scale is currently much too small to significantly affect the traditional egg market.

The Effect of a New Minimum Wage

The welfare effect of a new, higher minimum wage is illustrated in Figure 4. The graph on the left depicts Iowa's labor market and shows the equilibrium after wages increase from w^0 to w', the legal minimum. The minimum wage creates a wedge, ψ, between the quantity of labor demanded, x'^D, and the quantity of labor supplied, x'^S. Because employers will hire no more labor than is necessary, x'^S is irrelevant, and x'^D becomes the new quantity of working laborers in the state. The graph on the right in Figure 4 depicts the equilibrium in the Iowa's egg industry for the same minimum wage increase. The egg industry has a relatively steeper labor demand curve than the rest of the economy due to its relatively high dependence on human labor. An increase in wages results in fewer layoffs relative to other industries. This dependence on labor is exacerbated by the existence of more desirable jobs in non-rural locations throughout the state. Egg industry employers must pay a premium over other jobs to stay competitive with other employers.

In order to model how a minimum wage increase affects the egg industry, it is necessary to know whether the new minimum wage is binding. Clearly, it would be binding for the state labor market in general, otherwise there would be no reason to implement a minimum wage in the first place. Given the idiosyncrasies of the egg industry, however, a new minimum wage may or may not be binding. The graph on the right-hand side of Figure 4 shows that a minimum wage will bring about an inward shift in the labor supply curve. Recall how foodservice wages are currently lower than egg industry wages. A new minimum wage makes these non-egg industry positions relatively more attractive as the wage gap between the two begins to close. This shifts the egg industry's labor supply curve inward, which then increases the equilibrium wage. A minimum wage is binding if, after the supply curve shifts, the new equilibrium wage is still below the new minimum wage. This is depicted in Figure 4 by the shift in the supply curve from S to S'^{B}, and consequently the wage increase from w^0 to w'^{B}. Because this new, higher, equilibrium wage, w'^{B}, is still below the new minimum wage, the minimum wage is binding on the egg industry. If, on the other hand, the shift in the supply curve is from S to S'^{N}, the resulting wage, w'^{N} is above the new minimum wage, and thus the minimum is non-binding.

Given the scarce data on egg industry labor, predicting the exact magnitude of these shifts is difficult. Nonetheless, the distinction between binding and non-binding minimum wages plays an important role in this EDM. Specifically, scenarios with binding minimum wages require additional equations to account for the resulting wedge in the quantities of labor. Minimum wages that are not binding on the egg industry occur when egg industry wages end up above the new minimum wage. The following section describes the construction of these two versions of the egg industry EDM, but first, a brief discussion of the possible minimum-wage scenarios is helpful.

Consider scenario 1 as a binding minimum wage. Under this scenario, the new minimum wage is higher than the current equilibrium wage, even after the supply curve has shifted inward. An example would be $w^0 = \$13.50$ with a new minimum wage being \$15.00. The egg industry supply curve shifts inward as employees now have more acceptable job alternatives. This shift causes the equilibrium wage to rise to, say, \$14.50 (e.g., S'^{B} from the right-hand side of Figure

4). Because \$14.50 is still below the \$15.00 minimum wage, the minimum wage is binding, and it must be modeled with a wedge in labor quantities. A second scenario, scenario 2, occurs when, instead of \$14.50, the inward supply shift causes the equilibrium wage, w', to increase to, say, \$16.00 (e.g., S'^{N} from the right-hand side of Figure 4). Because \$16.00 is greater than \$15.00, the minimum wage is not binding, and thus scenario 2 can be modeled without a wedge. Obviously, this includes situations where the equilibrium wage is higher than the new minimum wage even before the supply curve shifts inward (i.e., where the new minimum wage is below the w^0 of \$13.50).

The Model for Non-Binding Minimum Wage Increases

Using the Atwood and Brester approach, based on the assumption of a linearly homogeneous production function, a one-output, one-input model is represented by the following equations:

$$E(q) = \eta E(p) + E(\theta_1) \quad (1)$$

$$E(p) = \kappa_1 E(w_1) + E(\theta_2) \quad (2)$$

$$E(x_1) = E(q) + \kappa_1 \sigma_{11} E(w_1) + E(\theta_3) \quad (3)$$

$$E(x_1) = \varepsilon_1 E(w_1) + E(\theta_4) \quad (4)$$

Note that $E(\cdot)$ represents percentage changes in its respective parameter. Equation (1) characterizes retail-level demand where p is output price and q is output quantity. Furthermore, η is the elasticity of demand and ε is the elasticity of supply. Equation (4) is the firm's input supply function, where w is the input price. Equation (2), is the firm's homogeneous of degree one production function, with κ representing the factor shares. Finally, equation (3) is the profit maximization problem's optimum conditions, where σ is the elasticity of substitution.

Exogenous shocks as percentage changes can be operationalized via each equation's respective θ term.

Equations (1) through (4) are used to construct a two-output, and three-input—hens, labor, and all other inputs—model to represent the Iowa egg industry. That model is as follows:

$$E(q_T) - \eta_T E(p_T) = E(\theta_1) \tag{5}$$

$$E(q_B) - \eta_B E(p_B) = E(\theta_2) \tag{6}$$

$$E(Q) - \left(\frac{q_T}{Q}\right) E(q_T) - \left(\frac{q_B}{Q}\right) E(q_B) = 0 \tag{7}$$

$$E(x_1) - \varepsilon_1 E(w_1) = E(\theta_3) \tag{8}$$

$$E(x_2) - \varepsilon_2 E(w_2) = E(\theta_4) \tag{9}$$

$$E(x_3) - \varepsilon_3 E(w_3) = E(\theta_5) \tag{10}$$

$$E(x_{1T}) - E(Q) - \kappa_{1T}\sigma_{11}E(w_1) - \kappa_{2T}\sigma_{12}E(w_2) - \kappa_{3T}\sigma_{13}E(w_3) = E(\theta_6) \tag{11}$$

$$E(x_{2T}) - E(Q) - \kappa_{1T}\sigma_{21}E(w_1) - \kappa_{2T}\sigma_{22}E(w_2) - \kappa_{3T}\sigma_{23}E(w_3) = E(\theta_7) \tag{12}$$

$$E(x_{3T}) - E(Q) - \kappa_{1T}\sigma_{31}E(w_1) - \kappa_{2T}\sigma_{32}E(w_2) - \kappa_{3T}\sigma_{33}E(w_3) = E(\theta_8) \tag{13}$$

$$E(x_{1B}) - E(Q) - \kappa_{1B}\sigma_{11}E(w_1) - \kappa_{2B}\sigma_{12}E(w_2) - \kappa_{3B}\sigma_{13}E(w_3) = E(\theta_9) \tag{14}$$

$$E(x_{2B}) - E(Q) - \kappa_{1B}\sigma_{21}E(w_1) - \kappa_{2B}\sigma_{22}E(w_2) - \kappa_{3B}\sigma_{23}E(w_3) = E(\theta_{10}) \tag{15}$$

$$E(x_{3B}) - E(Q) - \kappa_{1B}\sigma_{31}E(w_1) - \kappa_{2B}\sigma_{32}E(w_2) - \kappa_{3B}\sigma_{33}E(w_3) = E(\theta_{11}) \tag{16}$$

$$E(x_1) - \left(\frac{q_T}{Q}\right) E(x_{1T}) - \left(\frac{q_B}{Q}\right) E(x_{1B}) = 0 \tag{17}$$

$$E(x_2) - \left(\frac{q_T}{Q}\right) E(x_{2T}) - \left(\frac{q_B}{Q}\right) E(x_{2B}) = 0 \tag{18}$$

$$E(x_3) - \left(\frac{q_T}{Q}\right) E(x_{3T}) - \left(\frac{q_B}{Q}\right) E(x_{3B}) = 0 \tag{19}$$

$$E(p_T) - \kappa_{1T}E(w_1) - \kappa_{2T}E(w_2) - \kappa_{3T}E(w_3) = E(\theta_{12}) \tag{20}$$

$$E(p_B) - \kappa_{1B}E(w_1) - \kappa_{2B}E(w_2) - \kappa_{3B}E(w_3) = E(\theta_{13}) \tag{21}$$

Equations (5) to (21) provide the basis for analysis involving *shifts* in labor costs for egg producers. That is, these equations make up the model that examines non-binding minimum wage increases as well as any other labor supply-shifting events. Equations (5) and (6) represent the wholesale demand for table eggs and broken eggs, respectively. Equation (7) represents the sum of Iowa's table eggs and broken eggs. The inputs are: x_1 is the cost of procuring and maintaining the hens; x_2 is the cost of labor; and x_3 is all other costs (e.g., energy, cleaning supplies, etc.). Equations (8) to (10) represent the input supply functions. The corresponding first-order condition for each input are given in equations (11) through (13) for table eggs, and in equations (14) through (16) for broken eggs. Similar to equation (7), equations (17) through (19) simply aggregate the input quantities used for table eggs and broken eggs. The final two equations, (20) and (21), represent the egg producers' production function for table eggs and broken eggs respectively.

The variables in these equations are as follows: Q is the total wholesale quantity of eggs; p_T and p_B are the wholesale prices of table eggs and broken eggs respectively; x_i is the quantity of each input; and w_i is the cost of each input (i = hens, labor, other costs). The behavioral parameters of the model include η_i as the own-price elasticities of demand and ε_i as the elasticities of supply. The factor shares are represented by $\kappa_i = \left(\frac{w_i x_i}{wx}\right)$. Given the structure of the industry and the added steps required in producing broken eggs, the factor shares for table eggs are different than those for table eggs. Many previous vertical EDMs used τ, a price transmission term, to connect different levels of the supply chain while neglecting homogeneity. This model, however, incorporates verticality through its shocks. To minimize repetition, note that despite the slightly different makeups of the non-binding and the binding models, the approach for solving the system is identical.

The Model for Binding Minimum Wage Increases

The graph on the left-hand side of Figure 4 represents Iowa's labor market and provides an example of a binding minimum wage. In the figure, w^0 and x^0 represent the pre-minimum equilibrium wage rate and quantity, and the horizontal line at w' represents a new minimum wage. The introduction of the minimum wage alters the equilibrium, driving a wedge between x'^D and x'^S, the quantity demanded and supplied. This wedge, ψ, can be accounted for in the model by adding the following two equations:

$$E(x_2^S) - E(x_2^D) - E(\psi) = 0 \quad (22)$$

$$E(w_2) = E(\theta_{14}) \quad (23)$$

Equation (22) manifests the difference between the quantity of labor supplied and the quantity of labor demanded. Equation (23) provides the constraint. By adding equations (22) and (23), the binding model is fully-specified, and the system of equations can be solved using matrix algebra.

Equations (5) through (23) are shown in Appendix B in matrix form as $A \cdot Y = X$, where A is a 19×19 matrix of parameters, Y is a 19×1 vector of changes in the endogenous variables, and X is a 19×1 vector of exogenous shocks. In the binding minimum wage model, θ_{14} is the appropriate vehicle to implement the wage shock. In the non-binding model, θ_4 of equation (9) is the appropriate labor shock parameter. Assume, for example, in the non-binding model, the minimum wage is increased, causing labor costs to rise by 20%, i.e., $\theta_4 = 0.2$. The end result of this process is a Y vector that provides the percentage changes for each respective endogenous variable. In addition to the direct effect, there may be indirect effects of the minimum wage on the egg industry through the vertical chain, which is addressed in the next section.

Verticality and Supply Shocks in the Model

Iowa's egg production begins with Iowa egg breeders, and much of it ends with Iowa restaurants, institutions, and grocery stores. Because labor is a primary input in each of these sectors, an increase in Iowa's minimum wage is felt at all stages of vertical supply chain. This EDM model is a single-stage model and looks only at Iowa egg producers as opposed to breeders and retailers. Nonetheless, it incorporates the labor shock effects of the upstream firms as demonstrated in Figure 3 and discussed above.

Specifically, another shock is realized by the egg producer once the breeder raises its chick prices due to an increase in its labor costs. Because w_1 in this model denotes the egg producer's costs associated with hens, θ_3 from both models is the appropriate parameter to shock in order to model increased chick prices. This indirect shock to the egg producer's hen costs is smaller than the direct cost of labor shock due to a higher minimum wage. With scarce data and after speaking with the Egg Industry Center at Iowa State University, a shock that is 10% of the direct labor shock, seems to be an appropriate cost increase to procuring hens after a new minimum wage. Consequently, using the model, a projected 20% increase in labor costs is implemented by shocking θ_4 or θ_{14}, depending on which model, by 20%, and shocking θ_3 by 2%.

Discussion of Data and Model Parameters

Table 1 summarizes the parameters used in this model. Because public egg data is limited, elasticities are informed by the literature, and a sensitivity analysis is conducted. The own-price elasticity of demand is calculated using a weighted average of figures found in the literature, as shown in Table 1. The supply elasticities show the relationships between the quantity of inputs supplied and their respective prices. One would expect the elasticity of hen supply, ε_1, to be relatively inelastic as hens are the most essential part of egg production. The elasticity of labor supply is also quite inelastic, as many functions cannot be automated. Miscellaneous costs would be the least inelastic of the three-input supply elasticities. The factor shares are taken directly from Ibarburu, Schulz, and Imerman's (2019) budget of the Iowa egg industry. The Allen Elasticity of substitution (AES) is a measure of the substitutability between inputs. The first of these, $\sigma_{12} = \sigma_{21}$, that is, the elasticity of substitution between hens and labor is assumed to be relatively low at 0.1. Similarly, the substitutability between hens and other costs is also assumed to be low: $\sigma_{13} = \sigma_{31} = 0.1$. The AES between labor and all other costs would be higher: $\sigma_{23} = \sigma_{32} = 0.4$. Finally, note that σ_{11}, σ_{22}, and σ_{33} do not have a meaningful interpretation in that an input cannot be a substitute to itself. However, to keep the production technology homogeneous of degree zero in prices, these elasticities are calculated as follows: $\sigma_{11} = -\frac{(\kappa_2 * \sigma_{12}) + (\kappa_3 * \sigma_{13})}{\kappa_1}$, $\sigma_{22} = -\frac{(\kappa_1 * \sigma_{21}) + (\kappa_3 * \sigma_{23})}{\kappa_2}$, and $\sigma_{33} = -\frac{(\kappa_1 * \sigma_{31}) + (\kappa_2 * \sigma_{23})}{\kappa_3}$. The relative rankings of the elasticities are based on factor shares in the budget. Using data from Ibarburu, Schulz, and Imerman (2019), the factor shares for Iowa's entire egg industry are $\kappa_1 = 0.69, \kappa_2 = 0.08$, and $\kappa_3 = 0.23$.

While the data for calculating these more-specific factor shares are unavailable, one can be certain of the general direction that these numbers must be adjusted. Specifically, broken eggs require extra labor and extra inputs to carry out the additional required processes. As a result, the factor shares for broken eggs have a relatively smaller share for hens and larger shares for both labor and other costs. The converse is true for the factor shares of table eggs. In order to get a more accurate representation of the industry, this paper makes these adjustments while preserving a weighted average of factor shares that equals the industry level factor shares as calculated by Ibarburu, Schulz, and Imerman (2019). For table eggs, $\kappa_{1T} = 0.7367$, $\kappa_{2T} =$

0.0567, and $\kappa_{3T} = 0.2067$ are used. For broken eggs, the assumed factor shares are $\kappa_{1B} = 0.6700$, $\kappa_{2B} = 0.0900$, and $\kappa_{3B} = 0.2400$. The results provide two alternative sets of factor shares to provide a measure of sensitivity for these figures.

Results

As expected, the EDM model shows that increasing the cost of labor causes egg quantities to fall and prices to rise. In the long run, egg producers can adjust to increasing labor costs through several means, such as scaling their operations up or down, recalibrating their processes to be less dependent on labor, optimizing their allocations of investment given cost changes, or some combination of these options. In the short run, however, producers face a period of increased costs without the simultaneous benefit of increased output prices—especially producers under a production contract. Contract producers are unable to see the resulting output price increases until the beginning of their next contracting period. Even producers who do not contract must undergo the time period it takes for demand and supply forces to increase the price of their outputs. Meanwhile, producers must immediately finance their workers' pay increases. This immediate cost increase could result in budget shortfalls and potential closures of facilities. Of course, these shortfalls may be cushioned if a new minimum wage is introduced incrementally.

For a sensitivity analysis, the model included alternative parameter values, specifically the elasticity of labor supply, ε_2, the elasticity of substitution between hens and labor, σ_{12}, and the elasticity of substitution between labor and all other costs, σ_{23}. Each of these values is tested first in accordance with Table 1 and then at a figure that is 50% greater and one that is 50% smaller than what is given in Table 1. In addition, two alternate sets of factor shares for table eggs and broken eggs are provided to inform the sensitivity of the assumed values used. Note that changing ε_2 in a binding minimum wage model does not affect the outcome, thus it is not included in the sensitivity analysis for binding models.

Scenario 1: Results of a Binding Minimum Wage

In this scenario, Iowa raises its minimum wage to $15.00 an hour. If the minimum wage is binding, that means the resulting inward supply shift is not large enough to bring the equilibrium wage above $15.00 as shown in the supply curve S'^B on the right-hand side of Figure 4. The egg industry employers then must raise their wages further to at least $15.00 by law. Again, the significance of this being binding is that it drives a wedge between the quantities of labor demanded and supplied. To operationalize the wage of $15.00, note that $15.00 is an 11.11% increase from the assumed starting wage of $13.50. Consequently, the shocks are 0.1111 and 0.0111 for θ_{14} and θ_4, the shock parameters for the cost of labor, and for the cost of hens, respectively.

Table 2 shows that in a binding $15.00 minimum wage scenario, the decrease in the quantity of eggs produced in Iowa is about 146 million eggs—about an 0.86% reduction from Iowa's 2019 total egg production quantity. Broken eggs are affected more than table eggs owing to the relatively higher elasticity of demand. When η_B, the wholesale elasticity of demand for broken eggs is reduced by 50% to -0.401, the reduction of broken eggs with respect to table eggs is significantly more equitable. Retailers can expect to pay a price per dozen that is just over one cent higher, which is just over one percent above the average price of $1.05 a dozen. The percent increase for broken eggs is slightly higher at about 1.4%

As a higher minimum wage makes egg production more expensive, the quantity of eggs produced falls. As a result, the input quantities, x_i, also decrease. Table 2 shows a decrease in the quantity of all inputs, with labor being the most significant at 2.37%. Because the model shocked the costs of hens and labor, their total costs increase despite their decreased quantities. The cost of all other inputs, w_3, decreases directly related to the decrease in the quantity used, x_3. Looking at the alternative parameters in the sensitivity analysis, the most significant of these is η_B, the wholesale elasticity of demand for broken eggs. This is simply a result of broken eggs making up 70% of Iowa's total egg production.

Scenario 2: Results of a Non-Binding Minimum Wage

A minimum wage is non-binding when the new minimum wage is below the new equilibrium wage, w'. This was demonstrated by scenario 2. Because there exists no wedge between the labor supplied and demanded, this scenario can be modeled as simple shifts in the labor supply curve. This non-binding model can be useful outside of the context of a minimum wage and could examine the effects of any generic shift in the labor supply curve. For example, this model could be used to analyze the impacts of hypothetical immigration restrictions that lower the supply of labor in Iowa. Conversely, this model can also be used to analyze positive, outward shifts in the supply of labor.

Unlike the results for a \$15.00 an hour binding minimum wage, the results for the non-binding model are in terms of the percentage of labor supply shifts and not a specific minimum wage. Table 3 shows that an 11.11% (non-binding) negative shock to the labor supply curve causes a reduction of over 145 million eggs from production in Iowa—an 0.85% decrease. Similar to the binding model, wholesale table egg prices increase by about a cent, and broken egg prices per pound increase by about 1.39%. Despite the omission of the wedge equations, there are no significant deviations between the two models other than small differences in magnitudes—the two models are comparable. One should, however, consider the results of the non-binding model as the minimum effects. Given the fact that non-egg industry jobs seem to be more attractive when wages and benefits are equal, it is unlikely that the egg industry would not increase it wages even higher above a binding $15 minimum wage.

Conclusion

This research assessed the effects of a potential increase in labor costs as it pertains to the egg industry. This analysis was carried out using an equilibrium displacement model. In this model, wholesale supply and demand functions were estimated, linearized, and converted to elasticity form. The elasticities were mapped into matrix form to facilitate the solving of the system of equations. Demand and supply elasticities were used to calculate percentage changes for quantities and prices. These percentages were applied to egg price and quantity data to arrive at values for quantity losses and price increases.

When spread across the industry, the total negative effects due to increasing the minimum wage does not appear to be economically significant. This is due in large part to the Iowa egg industry's current equilibrium wage of $13.50 an hour. Consequently, imposing a $15.00 an hour minimum wage would be a difference of only $1.50 assuming the egg industry does not increase it further. In actuality, however, to stay competitive, egg industry employers would likely need to increase its wage to some level above $15.00 should the minimum wage be increased to that level. Despite these seemingly small effects, egg producers may nonetheless struggle in the short run to respond to immediate labor expenses should the state (or nation) not phase in its minimum wage over the course of several years. Most likely, if Iowa were to increase its minimum wage to $15.00 an hour, it would follow the lead of other states and incrementally increase its minimum wage over the course of many years until reaching $15.00.

Footnotes

[1]Appendix A contains a detailed description and overview of the U.S. industry.

[2]Appendix B contains a literature review of how EDMs were used over time and a complete mathematical derivation of the model to show that homogeneity has been imposed.

[3] Earlier models such as Gerra (1959) and Heady and Hayami (1962) contain information on labor that suggests that AES on labor and other inputs in egg production are likely to be low.

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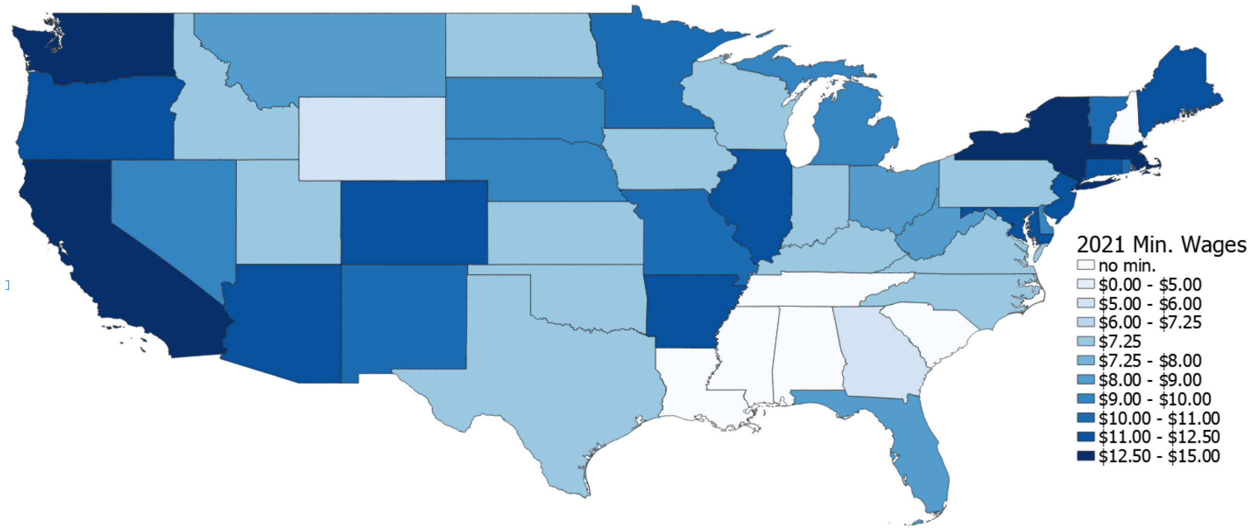
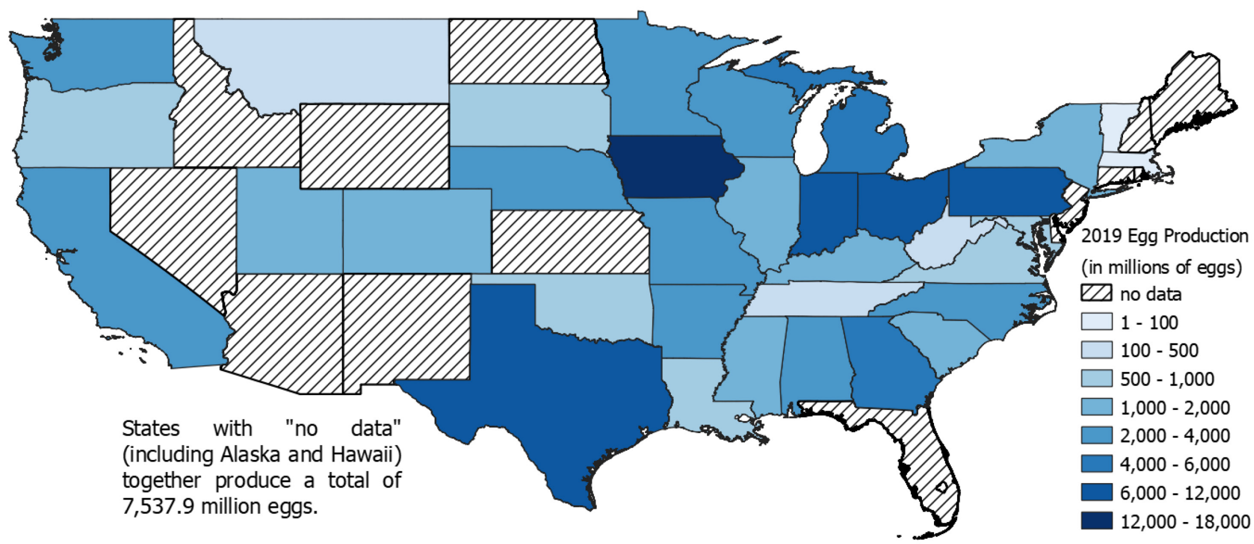
Figure 1. State Minimum Wages as Legislated for January 1, 2021



Source: Author’s depiction using National Conference of State Legislatures (NCSL) 2020 data

Figure 2. Egg Production by State (in millions of eggs)



Source: Author’s depiction using U.S. Department of Agriculture National Agricultural Statistics Service (2019) data

Figure 3. Graphical Analysis of an Inward-shift of Supply Functions of Upstream and Downstream Firms

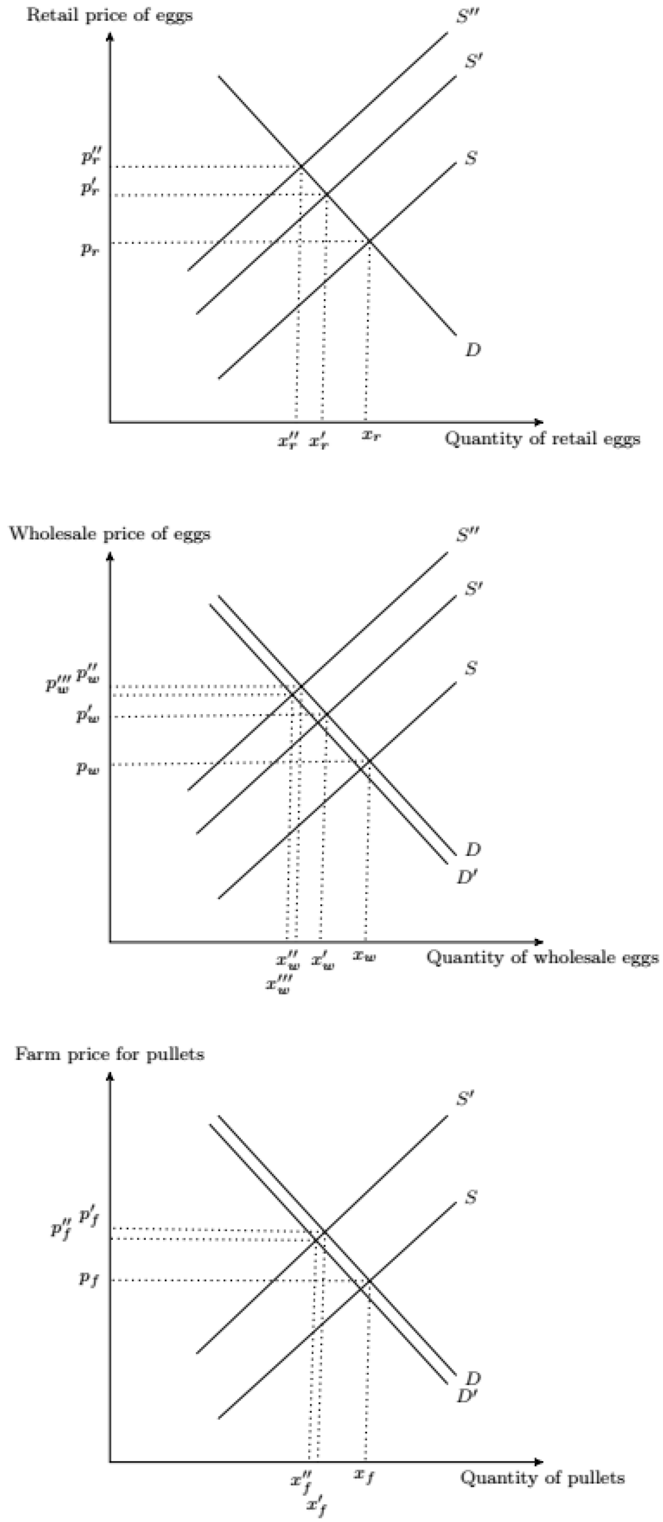


Figure 4. The Welfare Effects of a New Minimum Wage

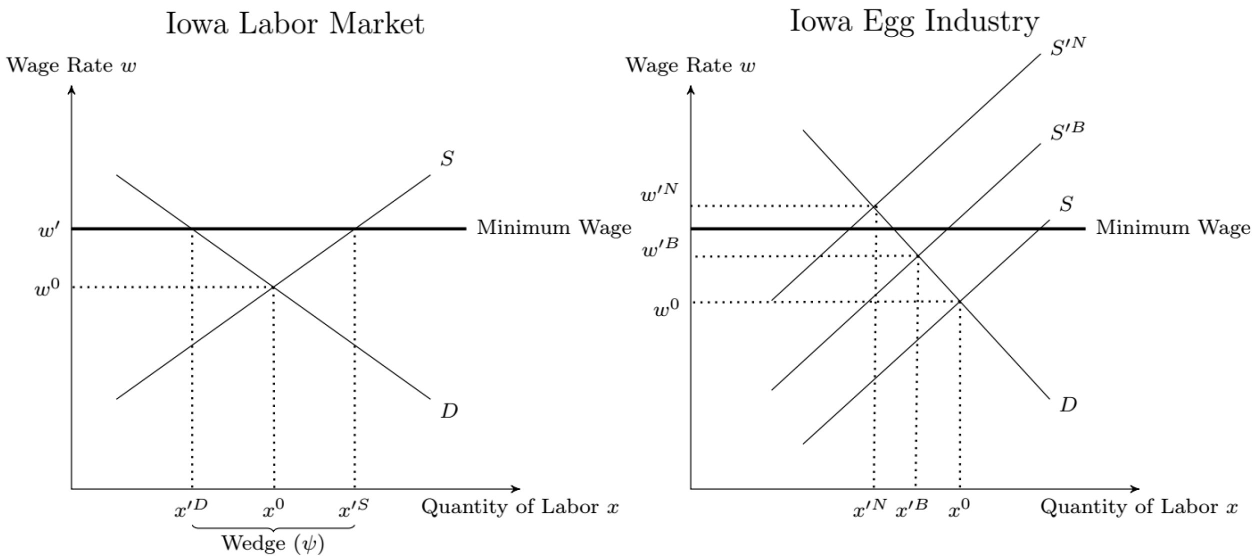


Table 1. Model Parameters, Definitions, and Sources

Parameter	Definition	Value	Source
E	Relative change operator	*NA*	*NA*
θ_i	Exogenous shifter	*NA*	*NA*
η_T	Wholesale own-price elasticity of demand for table eggs	-0.225	Various authors‡
η_B	Wholesale own-price elasticity of demand for broken eggs	-0.801	Thompson et al. 2019
ε_1	Elasticity of hen supply	0.4	Author's assumption
ε_2	Elasticity of labor supply	0.80	Author's assumption
ε_3	Supply elasticity of all other inputs	1.00	Author's assumption
κ_1	Factor share for the production of hens	0.69	Ibarburu, Schulz, and Imerman 2019
κ_2	Factor share of labor	0.08	Ibarburu, Schulz, and Imerman 2019
κ_3	Factor share of all other inputs	0.23	Ibarburu, Schulz, and Imerman 2019
σ_{11}	Elasticity of substitution (meaningless)	-0.03	Author's assumption
σ_{22}	Elasticity of substitution (meaningless)	-0.76	Author's assumption
σ_{33}	Elasticity of substitution (meaningless)	-1.18	Author's assumption
σ_{12}, σ_{21}	Elasticity of substitution between hens and labor	0.10	Author's assumption
σ_{13}, σ_{31}	Elasticity of substitution between hens and all other inputs	0.10	Author's assumption
σ_{23}, σ_{32}	Elasticity of substitution between labor and all other inputs	0.40	Author's assumption
Q	Total number of eggs produced in Iowa in 2019 (millions)	1,461.5	USDA NASS 2019
p_T	Average wholesale price per dozen eggs in Iowa in 2020	\$1.05	USDA ERS 2020
p_B	Average national wholesale price per pound of liquid eggs	\$0.55	USDA AMS 2019
q_T/Q	Percentage of eggs produced in Iowa that are table eggs	30%	Ibarburu, Schulz, and Imerman 2019
q_B/Q	Percentage of eggs produced in Iowa that are broken eggs	70%	Ibarburu, Schulz, and Imerman 2019

‡This figure is the mean of the literature's figures for the retail table egg elasticity of demand. The estimates used to calculate the table egg elasticities are from Andreyeva et al. (2010), Okrent and Alston (2012), and Thompson et al. (2019). The table egg elasticities of demand range from -0.08 to -0.73.

Table 2. Effects of a Binding Minimum Wage of $15.00

Change in:	**Base Model**	$\eta_T = -0.338$	$\eta_T = -0.113$	$\eta_B = -1.202$	$\eta_B = -0.401$	$\sigma_{12} = 0.15$	$\sigma_{12} = 0.05$	$\sigma_{23} = 0.45$	$\sigma_{23} = 0.15$	**Alt 1 κ†**	**Alt 2 κ‡**
Quantity of Table Eggs (millions), q_T	-12.647 [-0.247%]	-18.405 [-0.359%]	-6.524 [-0.127%]	-9.328 [-0.182%]	-18.048 [-0.352%]	-13.040 [-0.254%]	-12.647 [-0.247%]	-12.779 [-0.249%]	-12.512 [-0.244%]	-14.630 [-0.285%]	-15.456 [-0.302%]
Quantity of Broken Eggs (millions), q_B	-133.809 [-1.119%]	-130.878 [-1.094%]	-136.925 [-1.145%]	-162.020 [-1.355%]	-87.895 [-0.735%]	-136.698 [-1.143%]	-133.809 [-1.119%]	-135.383 [-1.132%]	-132.202 [-1.105%]	-129.800 [-1.085%]	-128.135 [-1.071%]
Quantity of Total Eggs (millions), Q	-146.456 [-0.857%]	-149.283 [-0.874%]	-143.449 [-0.840%]	-171.348 [-1.003%]	-105.944 [-0.620%]	-149.738 [-0.876%]	-146.456 [-0.857%]	-148.162 [-0.867%]	-144.714 [-0.847%]	-144.430 [-0.845%]	-143.591 [-0.841%]
Price of Table Eggs, p_T	$0.0115 [1.095%]	$0.0112 [1.062%]	$0.0119 [1.129%]	$0.0085 [0.807%]	$0.0164 [1.562%]	$0.0119 [1.129%]	$0.0115 [1.095%]	$0.0116 [1.106%]	$0.0114 [1.083%]	$0.0133 [1.266%]	$0.0140 [1.338%]
Price of Broken Eggs, p_B	$0.0077 [1.397%]	$0.0075 [1.366%]	$0.0078 [1.429%]	$0.0062 [1.128%]	$0.0101 [1.835%]	$0.0078 [1.427%]	$0.0077 [1.397%]	$0.0077 [1.413%]	$0.0076 [1.380%]	$0.0074 [1.355%]	$0.0073 [1.338%]
Quantity of Total Hens, x_1	-0.80%	-0.82%	-0.79%	-0.94%	-0.58%	-0.78%	-0.80%	-0.81%	-0.80%	-0.79%	-0.79%
Quantity of Total Labor, x_2	-2.37%	-2.39%	-2.35%	-2.55%	-2.08%	-2.74%	-2.37%	-2.77%	-1.96%	-2.36%	-2.35%
Quantity of Other Inputs, x_3	-0.49%	-0.51%	-0.47%	-0.65%	-0.24%	-0.51%	-0.49%	-0.38%	-0.61%	-0.48%	-0.47%
Quantity of Hens for Table Eggs, x_{1T}	-0.83%	-0.85%	-0.81%	-0.97%	-0.61%	-0.82%	-0.83%	-0.84%	-0.82%	-0.80%	-0.79%
Quantity of Labor for Table Eggs, x_{2T}	-1.92%	-1.94%	-1.90%	-2.10%	-1.62%	-2.18%	-1.92%	-2.21%	-1.62%	-2.20%	-2.35%
Quantity of Other Inputs for Table Eggs, x_{3T}	-0.57%	-0.59%	-0.55%	-0.73%	-0.31%	-0.58%	-0.57%	-0.49%	-0.65%	-0.51%	-0.47%
Quantity of Hens for Broken Eggs, x_{1B}	-0.79%	-0.81%	-0.78%	-0.93%	-0.57%	-0.77%	-0.79%	-0.80%	-0.79%	-0.79%	-0.79%
Quantity of Labor for Broken Eggs, x_{2B}	-2.57%	-2.59%	-2.54%	-2.75%	-2.27%	-2.99%	-2.57%	-3.01%	-2.11%	-2.42%	-2.35%
Quantity of Other Inputs for Broken Eggs, x_{3B}	-0.46%	-0.48%	-0.44%	-0.61%	-0.21%	-0.47%	-0.46%	-0.33%	-0.59%	-0.47%	-0.47%
Cost of Hens, w_1	0.77%	0.73%	0.81%	0.42%	1.33%	0.82%	0.77%	0.75%	0.79%	0.80%	0.81%
Cost of Other Inputs, w_3	-0.49%	-0.51%	-0.47%	-0.65%	-0.24%	-0.51%	-0.49%	-0.38%	-0.61%	-0.48%	-0.47%

† Alternative κ's are as follows: $\kappa_{1T} = 0.7133$, $\kappa_{2T} = 0.7207$, $\kappa_{3T} = 0.2146$, $\kappa_{1B} = 0.6800$, $\kappa_{2B} = 0.0834$, and $\kappa_{3B} = 0.2366$.

‡ Alternative κ's, here, are set equal to the Ibarburu, Schulz, and Imerman 2019 figures and do not differentiate between table and broken eggs, i.e., $\kappa_{1T} = 0.69$, $\kappa_{2T} = 0.08$, $\kappa_{3T} = 0.23$, $\kappa_{1B} = 0.69$, $\kappa_{2B} = 0.08$, and $\kappa_{3B} = 0.23$.

Table 3. Effects of a 11.11% Negative Shock to the Iowa Egg Industry Labor Supply Curve

Change in:	Base Model	$\eta_T = -0.338$	$\eta_T = -0.113$	$\eta_B = -1.202$	$\eta_B = -0.401$	$\varepsilon_2 = 1.2$	$\varepsilon_2 = 0.4$	$\sigma_{12} = 0.15$	$\sigma_{12} = 0.05$	$\sigma_{23} = 0.45$	$\sigma_{23} = 0.15$	Alt 1 κ†	Alt 2 κ‡
Quantity of Table Eggs (millions), q_T	-12.619 [-0.246%]	-18.358 [-0.358%]	-6.511 [-0.127%]	-9.308 [-0.182%]	-18.106 [-0.353%]	-12.030 [-0.235%]	-14.030 [-0.274%]	-12.924 [-0.252%]	-12.285 [-0.240%]	-12.673 [-0.247%]	-12.560 [-0.245%]	-14.574 [-0.284%]	-15.386 [-0.300%]
Quantity of Broken Eggs (millions), q_B	-133.036 [-1.112%]	-130.008 [-1.087%]	-136.258 [-1.139%]	-159.970 [-1.338%]	-88.389 [-0.739%]	-116.991 [-0.978%]	-171.491 [-1.434%]	-133.953 [-1.120%]	-132.034 [-1.104%]	-132.570 [-1.109%]	-133.548 [-1.117%]	-129.165 [-1.080%]	-127.560 [-1.067%]
Quantity of Total Eggs (millions), Q	-145.655 [-0.853%]	-148.366 [-0.868%]	-142.770 [-0.836%]	-169.279 [-0.991%]	-106.496 [-0.623%]	-129.021 [-0.755%]	-185.521 [-1.086%]	-146.877 [-0.860%]	-144.320 [-0.845%]	-145.242 [-0.850%]	-146.107 [-0.855%]	-143.739 [-0.841%]	-142.946 [-0.837%]
Price of Table Eggs, p_T	$0.0115 [1.092%]	$0.0111 [1.059%]	$0.0118 [1.127%]	$0.0085 [0.806%]	$0.0165 [1.567%]	$0.0109 [1.041%]	$0.0127 [1.214%]	$0.0117 [1.119%]	$0.0112 [1.063%]	$0.0115 [1.097%]	$0.0114 [1.087%]	$0.0132 [1.261%]	$0.0140 [1.332%]
Price of Broken Eggs, p_B	$0.0076 [1.389%]	$0.0074 [1.357%]	$0.0078 [1.422%]	$0.0061 [1.113%]	$0.0101 [1.845%]	$0.0067 [1.221%]	$0.0098 [1.790%]	$0.0077 [1.398%]	$0.0076 [1.378%]	$0.0076 [1.384%]	$0.0076 [1.394%]	$0.0074 [1.348%]	$0.0073 [1.332%]
Quantity of Total Hens, x_1	-0.80%	-0.82%	-0.78%	-0.93%	-0.58%	-0.73%	-0.96%	-0.77%	-0.83%	-0.80%	-0.80%	-0.79%	-0.79%
Quantity of Total Labor, x_2	-2.35%	-2.36%	-2.33%	-2.49%	-2.10%	-1.79%	-3.67%	-2.63%	-2.03%	-2.66%	-2.00%	-2.33%	-2.33%
Quantity of Other Inputs, x_3	-0.49%	-0.51%	-0.47%	-0.64%	-0.24%	-0.46%	-0.56%	-0.50%	-0.48%	-0.38%	-0.62%	-0.48%	-0.47%
Quantity of Hens for Table Eggs, x_{1T}	-0.83%	-0.84%	-0.81%	-0.96%	-0.61%	-0.75%	-1.00%	-0.81%	-0.84%	-0.82%	-0.83%	-0.80%	-0.79%
Quantity of Labor for Table Eggs, x_{2T}	-1.90%	-1.92%	-1.88%	-2.05%	-1.64%	-1.47%	-2.91%	-2.09%	-1.68%	-2.12%	-1.65%	-2.18%	-2.33%
Quantity of Other Inputs for Table Eggs, x_{3T}	-0.57%	-0.59%	-0.55%	-0.72%	-0.31%	-0.52%	-0.69%	-0.58%	-0.56%	-0.49%	-0.66%	-0.51%	-0.47%
Quantity of Hens for Broken Eggs, x_{1B}	-0.79%	-0.80%	-0.77%	-0.92%	-0.57%	-0.72%	-0.94%	-0.76%	-0.82%	-0.79%	-0.79%	-0.79%	-0.79%
Quantity of Labor for Broken Eggs, x_{2B}	-2.54%	-2.55%	-2.52%	-2.68%	-2.30%	-1.93%	-3.99%	-2.87%	-2.18%	-2.89%	-2.15%	-2.40%	-2.33%
Quantity of Other Inputs for Broken Eggs, x_{3B}	-0.46%	-0.47%	-0.44%	-0.61%	-0.21%	-0.44%	-0.50%	-0.47%	-0.44%	-0.33%	-0.60%	-0.47%	-0.47%
Cost of Hens, w_1	0.78%	0.74%	0.82%	0.44%	1.33%	0.95%	0.37%	0.84%	0.70%	0.78%	0.77%	0.80%	0.81%
Cost of Labor, w_2	10.96%	10.94%	10.98%	10.77%	11.26%	7.76%	18.61%	10.59%	11.35%	10.57%	11.39%	10.97%	10.98%
Cost of Other Inputs, w_3	-0.49%	-0.51%	-0.47%	-0.64%	-0.24%	-0.46%	-0.56%	-0.50%	-0.48%	-0.38%	-0.62%	-0.48%	-0.47%

† Alternative κ's are as follows: $\kappa_{1T} = 0.7133$, $\kappa_{2T} = 0.7207$, $\kappa_{3T} = 0.2146$, $\kappa_{1B} = 0.6800$, $\kappa_{2B} = 0.0834$, and $\kappa_{3B} = 0.2366$.

‡ Alternative κ's, here, are set equal to the Ibarburu, Schulz, and Imerman 2019 figures and do not differentiate between table and broken eggs, i.e., $\kappa_{1T} = 0.69$, $\kappa_{2T} = 0.08$, $\kappa_{3T} = 0.23$, $\kappa_{1B} = 0.69$, $\kappa_{2B} = 0.08$, and $\kappa_{3B} = 0.23$.

Appendix A

The U.S. Egg Industry

The egg industry in the United States (U.S.) is markedly different since 1995, the year of lowest per capita egg consumption at 232 eggs per person. This is compared with 402 eggs per person in 1945 and 279 eggs per person in 2018 (U.S. Department of Agriculture, Economic Research Service 2017). The increase in the consumption of eggs is due to an increase in food consumed away from home and the rise of the foodservice industry (e.g., restaurants, hospitals, prisons, schools) in general. Improvements in technologies that allow eggs to be sold in powdered or liquid form have resulted in increased use of alternative egg forms in retail outlets and have eliminated the need for retail workers to physically crack eggs. Studies have shown that despite potentially causing higher levels of dietary cholesterol, increased egg consumption has no statistically significant correlation with coronary artery disease (Rosenson and Song 2019).

Egg Breeder and Hatchery

The U.S. egg industry has become increasingly scientific about nutrition, genetics, housing, and other inputs related to laying hens. Yet, overall, the production system has remained the same since the modern production system emerged in the 1950s. The first step in egg production is the "breeding stage." Here, breeders use special breeds of egg-laying chickens and collect the resulting fertilized eggs. Next, at the hatchery, the eggs are incubated and hatched. In this step, workers sort the chicks into males and females through a process known as "sexing." The males are composted, and the females are sent to grower facilities off-site. For most of the industry, the breeding and the hatchery stages are owned and carried out by the same companies that are independent from the egg producers. These companies then sell the female chicks to egg producers.

Egg Production

Pullets are female chicks that are old enough to develop feathers but too young to lay full-sized eggs. During the "growing stage," the newly-acquired chicks are kept for many weeks, maturing into pullets. At 17 to 20 weeks of age, pullets are sent to the egg-laying facilities. Here, the hens have an egg-laying life of about 75 weeks before being replaced by fresh pullets from the grower facilities (Bell 2002). While many grocery stores offer different types of eggs (e.g., different colors, sizes, cage-free, organic, omega-3, etc.), each type's production process is similar except for locally-sourced or home-grown eggs. Even cage-free eggs share the same style of the supply chain as traditional eggs, aside from the structure of the laying facilities, which multiple studies have analyzed (Paarlberg, Seitzinger and Lee 2007, Sumner et al. 2011, Mullally and Lusk 2017). Because of the similarities between production processes, this dissertation aggregates and designates all these types of eggs as "table eggs."

At the egg-laying facility, and after the hens lay eggs, workers collect the eggs, wash them with sprays and brushes, candle and sort them, package them, and ship them to retail outlets.[1] Some facilities further process their eggs via breaker machines, creating liquid, powdered, or frozen eggs. Specifically, breakers crack the eggs and the liquid is gravity-fed into vats. Filters strain the egg liquid to remove shells, and the eggs are pumped through another filter to be cooled. Next, the egg liquid is pumped out and transported for pasteurization.

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[1] Candling refers to judging the quality of an egg's interior by use of bright light behind it. The task was originally done with candles.

Pasteurization requires a short period of high temperatures, followed by a longer period of relatively lower temperatures. At this point, the eggs are packaged in liquid form or can be frozen or dried. Frozen eggs have a longer shelf life than table eggs or liquid eggs, so long as they are kept at the correct temperature. Alternatively, the liquid eggs can be dried using a variety of methods to produce the form of eggs with the longest shelf life. Dried eggs can be further improved through the introduction of chemicals in order to extend shelf life, enhance flavor, and add vitamins, among other possibilities. We refer to processed eggs as "broken eggs" as opposed to the unbroken "table eggs" and refers to both as "eggs".

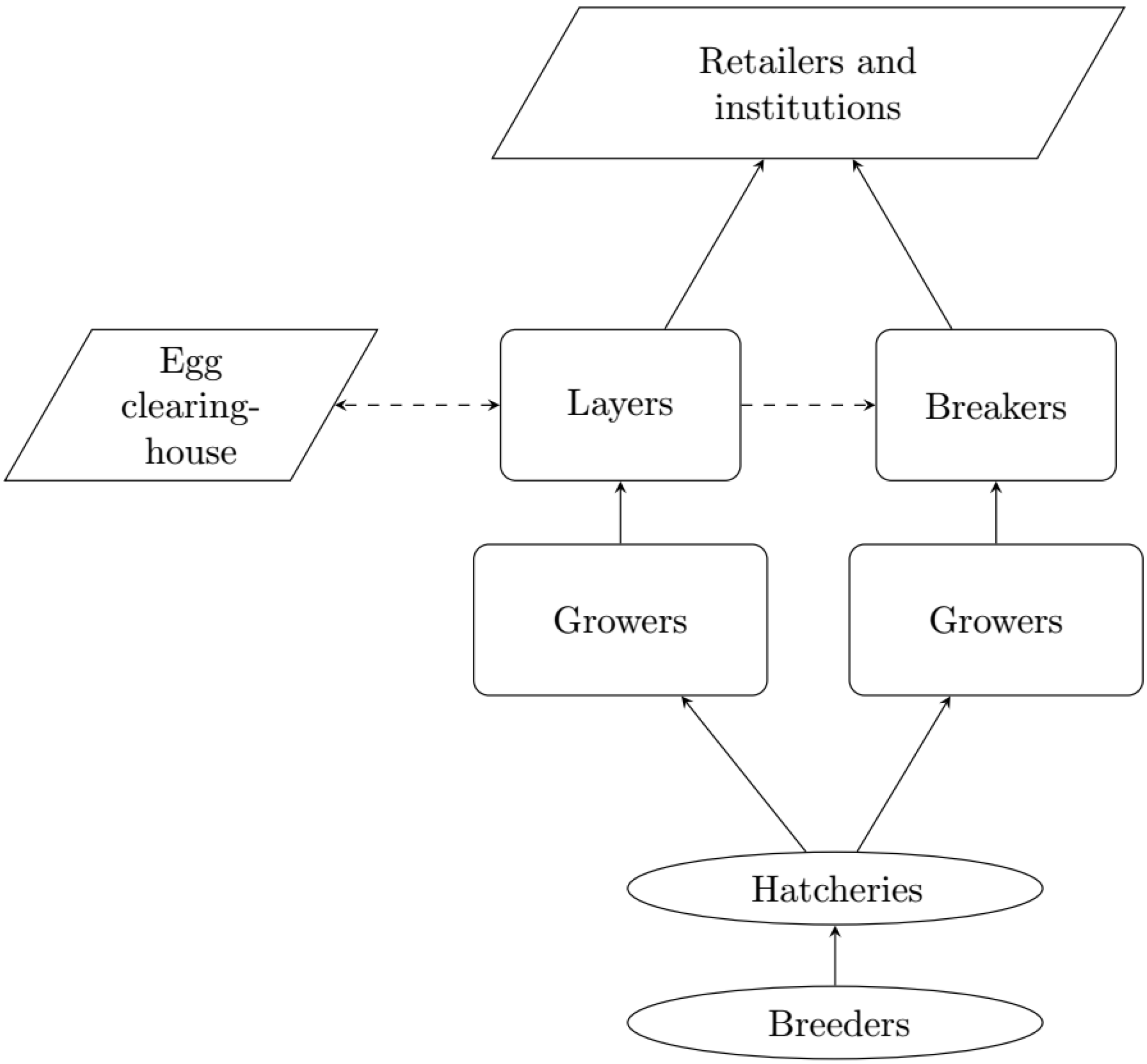
Egg Marketing and Distribution

The production of eggs from breeders to retailers involves the farm-level breeder/hatchery firm ("breeder") and the wholesale level grower/layer/breaker firm ("egg producer"), as shown in Figure A1. The eggs are sold to institution/restaurant/retailer firms ("retailer"). The egg producer has contracts with the breeder to secure the female chicks, as well as contracts with retailers to sell its eggs. A third-party organization known as the Egg Clearinghouse ("the clearinghouse") has emerged and facilitates the heavily-contracted egg industry (MacDonald, Hoppe, and Newton 2018). Egg producers that have, for whatever reason, produced above what is required by their marketing contracts with retailers can offload their excess table eggs at the clearinghouse. Conversely, the clearinghouse provides egg producers whose production has fallen short of their contractual obligations a means to easily cover their shortcomings. While the clearinghouse is an important part of the egg industry, it is not considered in this research.

Egg Production Costs

Although egg production costs are not widely published, recent papers confirm that current input expenditure proportions have changed little over time (Bell 2002; Ibarburu, Plastina and Vold 2019). In the U.S. egg industry, labor is the third largest variable cost of egg production, behind feed and pullets, and it is present in all stages of the value chain. From a manager's perspective, the cost of pullets is uninteresting, as pullets are essentially a fixed cost given the contractual nature of the industry. Specifically, in contract-type operations, the genetics providers often have a fixed price linked with the price of the output. All that is in the manager's control are the production operations themselves—finding efficiencies and engaging in production risk management. From this perspective, labor has a much larger share of the variable costs. Some of the workers' tasks include feeding, watering, and vaccinating the birds; collecting eggs; removing waste, carcasses, and spent hens; monitoring; cleaning and maintaining equipment; transporting chicks, pullets, hens, and eggs; and washing, grading, and packaging; among other tasks. Automation, such as using front-end loaders to collect poultry litter, instead of humans using pitchforks, has helped reduce overall labor costs, but the need for human workers still exists. Different jobs at a facility require different levels of skills, and as a result, varying wages.

Figure A5. The U.S. Egg Industry



Appendix B

Deriving the Basic Equilibrium Displacement Model

The basic equilibrium displacement model (EDM) is comprised of four primary equations:

$$q = q^D(p) \tag{B24}$$

$$x = x^S(w). \tag{B25}$$

$$q = f(x) \tag{B3}$$

$$pf_x - w = 0 \tag{B4}$$

where (B1) represents the demand for the output good, and (B2) represents the supply of the input, q^D is the output quantity demanded, p is the output price, x is the input quantity, and w is the input price. Equation (B3) is the production function and (B4) the optimum condition for the unconstrained profit maximization problem. The primary equations (B1)–(B4) can be mathematically manipulated into their final EDM forms of equations (B5)–(B8):

$$E(q) = \eta_D E(p) \tag{B5}$$

$$E(x_i) = \Sigma_j \kappa_j \varepsilon_{ij} E\left(w_j\right). \tag{B6}$$

$$E(p) = \Sigma_j \kappa_j E\left(w_j\right) \tag{B7}$$

$$E(x_i) = E(q) + \Sigma_j \kappa_j \sigma_{ij} E\left(w_j\right) \tag{B8}$$

Equations (B5)−(B8) are the basis for the EDM used in this research. The main text demonstrates how these equations can be further modified to represent the egg industry. The following describes the derivation of the basic EDM from the primary equations.

Deriving the Demand Equation

Start with the demand function in equation (B1):

$$q = q^D(p)$$

Totally differentiate the equation:

$$dq = \left(\frac{dq^D}{dp}\right) dp.$$

Divide both sides by q:

$$\frac{dq}{q} = \left(\frac{1}{q}\right) \frac{dq^D}{dp} dp.$$

Multiply the right-hand side by p/p:

$$\frac{dq}{q} = \left(\frac{1}{q}\right) \left(\frac{p}{p}\right) \frac{dq^D}{dp} dp.$$

Rearrange in order to put the equation into elasticity form:

$$\frac{dq}{q} = \left(\frac{dq^D}{dp} \frac{p}{q}\right) \left(\frac{dp}{p}\right).$$

Rewrite by inserting the appropriate elasticity symbols to get equation (B5)

$$E(q) = \eta_D E(p).$$

Deriving the Input Supply Equation

A similar approach is taken to derive the input supply function in equation (B6). Start with equation (B2)

$$x = x^S(w).$$

By total differentiation:

$$dx = \left(\frac{dx^S}{dw}\right) dw.$$

Divide both sides by x to get:

$$\frac{dx}{x} = \left(\frac{1}{x}\right) \frac{dx^S}{dw} dw$$

Multiply the right-hand side by w/w to get:

$$\frac{dx}{x} = \left(\frac{1}{x}\right)\left(\frac{w}{w}\right)\frac{dx^S}{dw}dw.$$

Rearrange in order to put the equation into elasticity form:

$$\frac{dx}{x} = \left(\frac{dx^S}{dw}\frac{w}{x}\right)\left(\frac{dw}{w}\right)$$

Rewrite by inserting the appropriate elasticity symbols to get:

$$E(x) = \varepsilon^S E(w)$$

Finally, for the case of n inputs, the elasticity of supply is replaced by the weighted sum of input supply elasticities, weighted by factor share κ_j, so as to arrive at equation (B6):

$$E(x_i) = \sum_j \kappa_j \varepsilon_{ij}\, E(w_j) \text{ for } i = 1,2, \dots, n.$$

Deriving the Optimum Condition and Production Function

Starting with the production function (B3) and the optimum condition (B4), take the total differentials:

$$dq = f_x dx$$

$$f_x dp + p f_{xx} dx - dw = 0.$$

These two equations can be put into matrix form:

$$\begin{bmatrix} 0 & f_1 & f_2 & \cdots & f_n \\ f_1 & pf_{11} & pf_{12} & \cdots & pf_{1n} \\ f_2 & pf_{21} & pf_{22} & \cdots & pf_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ f_n & pf_{n1} & pf_{n2} & \cdots & pf_{nn} \end{bmatrix} \begin{bmatrix} dp \\ dx_1 \\ dx_2 \\ \vdots \\ dx_n \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & \cdots & 0 \\ 0 & 1 & 0 & \cdots & 0 \\ 0 & 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & 1 \end{bmatrix} \begin{bmatrix} dq \\ dw_1 \\ dw_2 \\ \vdots \\ dw_n \end{bmatrix}. \qquad \text{(B9)}$$

The system in (B9) has four matrices—two of which are vectors, and one is an identity matrix. From left to right, they are in the form $A \cdot B = I \cdot X$. Ignoring I, the identity matrix (its presence does not affect the outcome), the explicit solutions for this system of equations can be found by solving for the B vector: $B = A^{-1} \cdot X$. The results are expressed in terms of q and w:

$$p = p^*(q, w) \quad \text{(B10)}$$

$$x = x^*(q, w). \quad \text{(B11)}$$

To solve the system, take the total differential of each solution, (B10) and (B11), to get

$$dp = \left(\frac{\partial p^*}{\partial q}\right) dq + \Sigma_j \left(\frac{\partial p^*}{\partial w_j}\right) dw_j \quad \text{(B12)}$$

$$dx_i = \left(\frac{\partial x_i{}^*}{\partial q}\right) dq + \Sigma_j \left(\frac{\partial x_i{}^*}{\partial w_j}\right) dw_j. \quad \text{(B13)}$$

From these two equations, $\left(\frac{\partial p^*}{\partial q}\right)$, $\left(\frac{\partial p^*}{\partial w_j}\right)$, $\left(\frac{\partial x_i{}^*}{\partial q}\right)$, and $\left(\frac{\partial x_i{}^*}{\partial w_j}\right)$ are of interest. With some algebra it can be shown that the values of the derivatives are:

$$\left(\frac{\partial p^*}{\partial q}\right) = 0,$$

$$\left(\frac{\partial x_j{}^*}{\partial q}\right) = \left(\frac{\partial p^*}{\partial w_j}\right) = \frac{x_j}{q}, \quad \text{(B14)}$$

and $\left(\frac{\partial x_i{}^*}{\partial \mathrm{w_j}}\right) = \frac{\kappa_j \sigma_{ij} x_i}{w_j}$.

Hence,

$$dp = (0)dq + \Sigma_j \left(\frac{x_j}{q}\right) dw_j = \Sigma_j \left(\frac{x_j}{q}\right) dw_j \quad \text{(B15)}$$

$$dx_i = \left(\frac{x_j}{q}\right) dq + \Sigma_j \left(\frac{\kappa_j \sigma_{ij} x_i}{w_j}\right) dw_j. \quad \text{(B17)}$$

These expressions can be converted to EDM form:

$$\frac{dp}{p} = \Sigma_j \frac{w_j x_j}{pq} \frac{dw_j}{w_j} = \Sigma_j \frac{w_j x_j}{w \cdot x} \frac{dw_j}{w_j} = \Sigma_j \kappa_j \frac{dw_j}{w_j} = \Sigma_j \kappa_j E(w_j) \quad \text{(B18)}$$

$$\frac{dx_i}{x_i} = \frac{1}{q} dq + \Sigma_j \frac{\kappa_j \sigma_{ij}}{w_j} dw_j = \frac{dq}{q} + \Sigma_j \kappa_j \sigma_{ij} \frac{dw_j}{w_j} = E(q) + E_j \kappa_j \sigma_{ij} E(w_j). \quad \text{(B19)}$$

Equations (B18) and (B19) show the EDM versions of the production function and optimum conditions, respectively.