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The Cost and Market Impacts of Slow-Growth Broilers

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There has been substantial productivity growth in the broiler industry; however, high growth rates might adversely affect animal welfare, resulting in calls for slow-growth breeds. This research shows production costs are 11%–25% per pound higher for slower-growing breeds than for modern breeds, depending on the target endpoint. Breakeven wholesale price premiums needed equate net returns of slow- to fast-growth broilers range from $0.10/lb to $0.36/lb. Annual costs of an industry-wide conversion to slow growth are $450 million for consumers and $3.1 billion for producers. Consumer willingness-to-pay would need to increase 10.8% to offset the producer losses.

Key words: animal welfare, broiler, production cost, slow growth

Introduction

The broiler industry experienced rapid productivity growth during the latter half of the twentieth century. Since the 1950s, broiler body weight at 6 weeks of age has increased more than 3.3% per year, and the amount of feed needed to reach a target weight has fallen by half (Zuidhof et al., 2014). The aggregate impacts have been substantial. Total poultry and egg output in the United States increased more than 650% from 1948 to 2015 (U.S. Department of Agriculture, 2018a), and the value of the partial productivity gains for the broiler industry from 1980 to 2012 have been estimated at $12.8 billion/year (Lusk, 2013). These gains in productivity led to a 47% reduction in the real price of poultry from 1960 to 2010, and chicken is now the most-consumed animal protein in the United States (U.S. Bureau of Labor Statistics, 2018; U.S. Department of Agriculture, 2018b). Despite the consumer benefits that have accrued from lower chicken prices and the resource savings from increased feed efficiency and growth, there are concerns that animal welfare has deteriorated.

While modern broilers only live about 6 weeks, there are concerns that the birds' legs are unable to adequately support the larger bodyweights, leading to pain and an inability to exhibit natural behaviors (e.g., de Jong et al., 2012; Sanotra et al., 2001; SCAHAW, 2000). As a result of such findings, animal advocacy organizations have begun to pressure food retailers to use slower-growing breeds (e.g., Trotter, 2018), European regulators have encouraged slow-growth broilers (European Council, 2007), national media attention has begun to focus on the issue (Charles, 2016; Strom, 2017), some major poultry producers—such as Perdue Farms—are researching slower-growing breeds, and some animal welfare standards and labels have begun to require slower-growing broiler breeds (Global Animal Partnership, 2018). There has been some consumer research on demand for this attribute (e.g., Carlsson, Frykblom, and Lagerkvist, 2007; Lusk, 2018; Napolitano et al., 2013), but little is known about the added production costs associated with slow-growth chickens. What little information exists comes from an industry report (Elanco Animal Health, 2016), which formed the basis of an infographic by the National Chicken Council (2017a) that was critical of slow-growth

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broilers. As retailers and poultry producers consider pledges to move to slow-growth chickens, a key unknown relates to the added costs of production.

The primary objective of this research is to determine the production costs and breakeven price premiums for slow-growth chicken breeds relative to modern fast-growth breeds. Once these outcomes are determined, this research uses an equilibrium displacement model to determine the market impacts of an industry-wide shift away from modern breeds toward slow-growth breeds. Cost and market outcomes are calculated for three scenarios that involve different behavioral assumptions on the part of broiler producers: (i) feeding broiler flocks for a fixed number of days (either 6 or 7 weeks), (ii) feeding broiler flocks until they reach a target weight (6 lb), or (iii) feeding flocks until net partial returns are maximized. Results are also analyzed using different assumptions about stocking densities given that adoption of slow-growth breeds is often accompanied by reductions in stocking density motivated by animal welfare concerns.

Methods

A few studies have created budgets for broiler producers (e.g., Goodwin et al., 2005; Rhodes et al., 2011), but the costs of production are constructed from the perspective of a contractor who is provided feed, chicks, and other inputs from an integrator. Given the importance of feed costs, and the fact that slower and faster-growing breeds have different feed efficiencies, a broader perspective is required. As a result, this analysis takes a holistic approach to determining costs associated with the broiler growth phase of the production process, including the opportunity costs of the birds, the barn, and the feed. No attempt is made to segregate or allocate the costs or returns to the integrator versus the contractor.

One of the drivers of relative profitability in slow- and fast-growing broiler breeds is barn utilization. If faster-growing breeds allow more broilers to be fed during the course of a year than slow-growing breeds, then a greater amount of output can be produced in a barn with faster-growing breeds compared to slower-growing breeds. Rather than specifying a particular barn size and calculating outputs per barn, focus is on impacts on a square footage basis, which permits greater generalizations. Let τ be the number of flocks (i.e., the number of times a batch of broilers is brought into a barn [or a given square foot]) per year. There are

$$\tau = 365/(d + down) \tag{1}$$

flocks per year, where d is the number of days each flock is fed before harvest and *down* is the number of days of downtime required to transition the barn (or square foot) from one flock to another.

Now consider total meat production:

$$q_d = wt_d \times yield_d \times sden_d \times \tau, \tag{2}$$

where q_d (lb/ft^2/year) is total output of a flock fed for d days, wt_d (lb/broiler) is a broiler's live body weight on day d, $yield_d$ is the dressing percentage expressed as the ratio of a broiler's dressed weight to live weight on day d, and $sden_d$ (broilers/ft^2) is the maximum allowable stocking density defined by animal welfare guidelines and determined by live weight at the final day on feed (as discussed momentarily, stocking density is often defined in the industry as weight per square foot, which is subsequently converted to broilers per square foot for these calculations).

Once total production is known, then revenue, R_{td} (\$/ft^2/year), at time t for flocks fed d days can be calculated as

$$R_{td} = p_t \times q_d, \tag{3}$$

where p_t is the output price (\$/lb) of wholesale processed broilers and q_d is defined by equation (2). The time subscript t is added to allow for the fact that prices change throughout time; this is distinct from d, which is the total number of days a flock is on feed.

Cumulative variable costs, C_{td} (\$/ft^2/year), at time t for flocks fed d days are

$$C_{td} = \tau \times \left[\beta + sden_d \times \left(w_t \times \sum_{i=0}^{d} x_i + \alpha \times d + chick \right) \right], \tag{4}$$

where τ is the number of flocks per year, defined in equation (1); β (\$/ft^2) is the cost of transitioning from one flock to another (e.g., clean-up and preparation costs); $sden_d$ (broilers/ft^2) is the stocking density; w_t (\$/lb) is the price of feed; x_i (lb/broiler) is a broiler's feed intake on day i, making $\sum_{i=0}^{d} x_i$ a broiler's cumulative feed intake (\$/broiler) through d days; α is an additional daily cost (\$/broiler/day) that arises from electricity, labor, interest on the barn, etc.; and $chick$ is the price or opportunity cost (\$/chick) of new replacement broilers.

Taking the ratio of equation (4) to equation (2) provides the estimated cost per pound of production, Clb_{td} (\$/lb), at time t for broilers fed d days:

$$Clb_{td} = C_{td}/q_d. \tag{5}$$

Finally, subtracting equation (4) from equation (3) provides estimated net partial returns, π_{td} (\$/ft^2/year):

$$\pi_{td} = R_{td} - C_{td}. \tag{6}$$

These are only partial returns because they do not include fixed costs or other time-invariant costs that are the same regardless of which broiler breed is used for production.

A final metric of interest is the breakeven output price premium, $\tilde{p}$. This is the difference in output prices (\$/lb) that equates the partial return of higher- and lower-performing broiler breeds. Let $b1$ and $b2$ indicate two broiler breeds, where $b2$ has a higher return than $b1$. The task is to find the price difference, such that $\pi_{td}^{b1} = \pi_{td}^{b2}$, where the superscripts denote the breeds. Solving this equation yields the breakeven output price premium:

$$\tilde{p}_{td} = \frac{\pi_{td}^{b2} - C_{td}^{b1}}{q_d^{b1}} - p_t^{b1}. \tag{7}$$

In the analysis that follows, we compare outcomes under different scenarios according to different behavioral assumptions about broiler producer behavior. First, the above equations are calculated assuming producers feed broilers for a targeted or fixed number of days on feed. In particular, we assumed $d = 42$ (6 weeks) and $d = 49$ (7 weeks). These values are chosen because 7 weeks is approximately the average time for a flock to be fed (MacDonald, 2014), even though 6 weeks is a common stopping point under high-productivity conditions. Of course, slower-growing broilers will weigh less at a fixed number of days than faster-growing birds. As a result, a second behavioral rule for producers is considered consistent with the idea that, at a particular processing time, packers prefer to utilize flocks of a homogeneous size to minimize production and processing costs. In particular, outcomes are evaluated on the day d when live weight, wt_d, first exceeds 6 lb, which is about the industry average for the past several years (National Chicken Council, 2018). Observation of market outcomes reveals wide variation in chicken sizes in the marketplace, suggesting different consumer segments prefer different sizes; however, this paper focuses specifically on the broiler segment (as opposed to capons, roasters, or Cornish), for which 6 lb is a common end weight. Third, we compare outcomes across different broiler breeds when d is chosen to maximize the net partial returns defined by equation (6).

The first three scenarios assume a fixed stocking density for each breed so that *ceteris paribus* comparisons can be made and differences in costs and returns are driven only by performance. However, it is important to realize that adoption of slow-growth breeds is typically accompanied with stocking density restrictions. As such, the final scenario repeats the exercise of choosing optimal net returns, except (consistent with industry standards) different stocking densities are used for slow- and fast-growth breeds. Each of these four scenarios is compared at different input and output prices at different points in time, t.

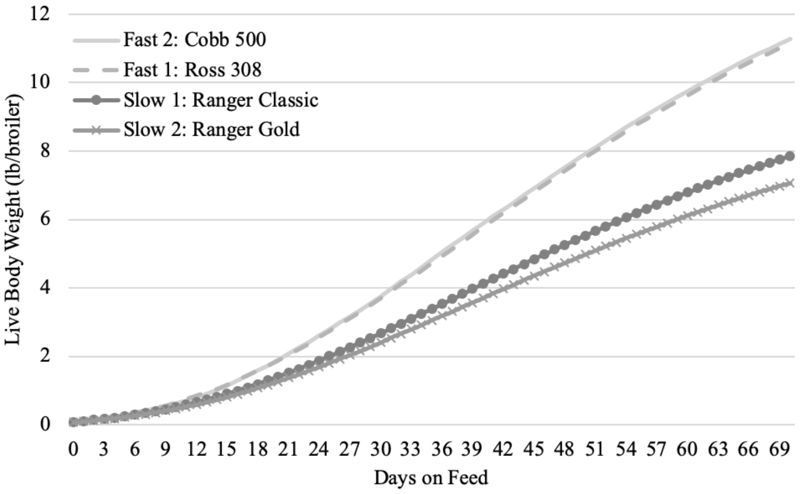

Figure 1. Growth Curves for Commercial Slow- and Fast-Growing Broiler Breeds

Data

At present, there is no uniform definition for slow-growth broilers, but more than 25 organizations have signed a letter referred to as the ECC (2018) or the "European Broiler Ask," which references seven specific breeds; two of these (Ranger Classic and Ranger Gold) are used to represent slow-growth broiler performance in this study. Performance data for Ranger Classic and Ranger Gold and for two widely used, modern fast-growing broiler breeds (Ross 308 and Cobb 500) were obtained from the respective companies (Aviagen, 2014, 2018a,b; Cobb-Vantress, 2015). These data consist of a broiler's body weight, wt_d, by day on feed for broilers "as hatched" (i.e., mix of male and female broilers). Figure 1 shows the growth curves relating wt_d to d for each of the four breeds studied in this paper. As advertised, the slower-growing Ranger Gold and Ranger Classic broilers have lower body weights than the faster-growing breeds, Ross 308 and Cobb 500. The slower-growing breeds take 54 and 59 days, respectively, to reach 6 lb, whereas the faster-growing breeds both hit this target weight in about 41 days.

The growth rates of the fast-growing breeds are consistent with that reported in previous scientific studies (e.g., Zuidhof et al., 2014) and with personal experience; however, they are higher than what has been reported in some analyses of commercial operation performance. For example, using 2011 data, MacDonald (2014) shows that commercial operations tend to hit about 6 lb in 48 days, on average, which is 6 days longer than suggested in Figure 1. The difference may be partially explained by the fact that breeders' production data reflect "high-quality" conditions related to ventilation, feed, water, temperature, etc. The key issue for the present paper is that the production data for both slow- and fast-growing breeds comes from "high-quality" conditions. That is, the conditions are held constant in our comparison of slow- versus fast-growing broilers, and as such there is no confound. Nonetheless, the absolute performance of both slow- and fast-growing breeds reported in this paper may be higher than what would be expected given some commercial conditions.

Performance data from commercial breeders also provides information on daily feed intake, x_d, and $yield_d$. The data on yield from the breeders are only provided in categories for different body weights, and by gender, so regressions are used to provide a yield estimate at each body weight (estimated as a quadratic equation), which is a function of d, and then the prediction is averaged for males and females. Performance data for the two slow-growing breeds and for Ross 308 are available for days 0–70, but for Cobb 500, data is only reported up to 63 days on feed. For uniform comparisons, cubic trend regressions were used to project performance out to 70 days for Cobb 500.

Monthly data on output prices for broilers, p_t, were obtained from January 2000 to September 2018 ($N = 225$). Georgia dock wholesale prices for whole broilers are used up until April 2012, after which the USDA National Composite Weighted Average wholesale broiler price was used (e.g., see U.S. Department of Agriculture, Agricultural Marketing Service, various years). The USDA reported a slightly different wholesale broiler price series (the national 12-city average), which was discontinued at the end of 2012, and the Georgia dock price ceased being reported at the end of 2016. Over the time period in question, the wholesale price of whole broilers averaged \$0.81/lb, with a low of \$0.56/lb and a high of \$1.19/lb.

To calculate a feed price, monthly average data were obtained from January 2000 to September 2018 on nearby futures prices for corn, soybean meal, and soybean oil, each of which was converted to dollars per pound (it was assumed ground corn was used, such that 1 bushel = 48 lb of ground corn). A weighted average feed price was calculated assuming a feed ration of 55% ground corn, 35% soybean meal, 5% soybean oil, and 5% other ingredients and additives (the latter of which was assumed to be priced at a fixed \$0.02/lb). Over the 225 months in question, the calculated feed price averaged \$0.11/lb (equivalent to an average of \$221/ton) and varied from a low of \$0.05/lb to a high of \$0.21/lb (or \$112/ton to \$426/ton).

Data reported by Goodwin et al. (2005), MacDonald (2014), and Rhodes et al. (2011), were used to guide the choice of other values used in the model. In particular, we assumed a flock transition time of 14 days ($down = 14$), a flock transition cost of \$0.015/ft^2 ($\beta = 0.015$), an opportunity cost of placement chicks of \$0.90/broiler ($chick = 0.9$), and an additional daily cost of \$0.0025/broiler/day ($\alpha = 0.0025$). MacDonald (2014) reports an average industry turnaround of 16 days, with 25% of producers experiencing 14 days or less downtime between flocks. We choose 14 days rather than the 16 reported in MacDonald because it is a realistic transition time and because MacDonald's data were collected in the midst of a global recession and an associated broiler production downturn that likely led to longer than usual turnaround times.

For the first three scenarios, stocking densities were determined by the National Chicken Council (2017b) Animal Welfare Guidelines, which specify a maximum stocking density of 8.5 lb/ft^2 for conventional broilers raised to final weights of 5.6–7.5 lb/broiler (measured at the final day on feed). Assuming producers will stock up to the weight limit implies that on final day d, the stocking density will be $sden_d = 8.5/wt_d$ broilers/ft^2. Given that the industry defines stocking density limits on a weight basis suggests that there will be more slow-growth broilers (which are lighter on a given day) per square foot than fast-growth broilers.[1] For the fourth scenario, we incorporate the observation that adoption of slow-growth breeds is typically accompanied with additional standards for lower stocking densities. In particular, the Global Animal Partnership (2018) mandates a maximum stocking density of 6 lb/ft^2. Assuming again that producers will stock up to this limit implies a stocking density of $sden_d = 6/wt_d$ broilers/ft^2 for slow-growth breeds.

Market Impacts

To determine the market impacts of a complete industry shift from fast- to slow-growth broilers, caused either by retailer or by food manufacturer demands, we construct a partial equilibrium model of the broiler-chicken industry. In particular, we construct an equilibrium displacement model, which expresses proportionate changes in market prices and quantities as a function of elasticities and exogenous supply/demand shifts, following Wohlgenant (1993, 2011) and Lusk and Anderson

[1] This stocking density choice is on par with that assumed in other budget studies, such as Rhodes et al. (2011), but implies a higher stocking density than what is suggested in industry surveys such as MacDonald (2014). The choice of stocking density will have an influence on any variable measured on a square footage basis (e.g., pounds of production per square foot), but the choice has trivial effects on the main metrics of interest, which are ratios. For example, the estimated cost per pound is only about \$0.0007/lb higher for each breed, assuming a stocking of 6.5 lb/ft^2 instead of 8.5 bs/ft^2 when all flocks are on feed 49 days. Breakeven price premiums are likewise unaffected by choice of stocking density.

(2004). Retail demand for chicken in the United States is given by

(8) $$\hat{Q} = \eta\left(\hat{P} - \delta\right),$$

where $\hat{Q}$ and $\hat{P}$ are the proportionate changes in the retail quantity and price of chicken (e.g., $\hat{Q} = \Delta Q/Q$), respectively; η is the own-price elasticity of demand for chicken; and δ is an exogenous demand shock representing a proportionate increase in consumer willingness-to-pay. The supply of chicken and the demand for broilers are given by

(9) $$\hat{P} = S\hat{w} \text{ and}$$

(10) $$\hat{x}_d = -(1-S)\,\sigma\hat{w} + \hat{Q},$$

where $\hat{x}_d$ is the proportionate change in the quantity of broilers supplied to the domestic market, $\hat{w}$ is the proportionate changes in the price of broilers, S is the share of the total cost of producing chicken attributable to broilers, and σ is the elasticity of substitution between broilers and marketing inputs in producing chicken (see Wohlgenant, 1993, for details). The supply of broilers by U.S. producers is

(11) $$\hat{x} = \varepsilon(\hat{w} - k),$$

where ε is the own-price supply elasticity and k is an exogenous supply shifter. The total supply, $\hat{x}$, is distributed to domestic and foreign sources as follows:

(12) $$\hat{x} = S_d\hat{x}_d + (1 - S_d)\hat{x}_f,$$

where $\hat{x}_f$ is the quantity supplied to foreign sources and S_d is the share of U.S. broiler production going to domestic consumers. Finally, demand by foreign consumers for U.S. broilers is

(13) $$\hat{x}_f = \gamma\hat{w},$$

where γ is the own-price elasticity of export demand.

Equations (8)–(11) represent a system of six equations with six unknown endogenous variables, $\hat{Q}$, $\hat{P}$, $\hat{x}$, $\hat{x}_d$, $\hat{x}_f$, and $\hat{w}$, which can be solved algebraically. Once solutions to the endogenous variables are determined, changes domestic consumer surplus, foreign consumer surplus, and producer surplus are (see Wohlgenant, 1993, 2011)

(14) $$\Delta CS_d = -P^0Q^0\left(\hat{P} + \delta\right)\left(1 + 0.5\hat{Q}\right),$$

(15) $$\Delta CS_f = -w^0x_f^0\left(\hat{w}\right)\left(1 + 0.5\hat{x}_f\right), \text{ and}$$

(16) $$\Delta PS = w^0x^0\left(\hat{w} - k\right)\left(1 + 0.5\hat{x}\right),$$

where P^0Q^0 is represents total U.S. consumer expenditures on chicken, $w^0x^0$is the value of U.S. boiler production, and $w^0x_f^0$ is the value of U.S. broiler exports. The change in producer surplus reported in equation (16) includes the effects on suppliers of all inputs to broiler production including landowners, lenders, contract labor, integrators, etc. (Just, Hueth, and Schmitz, 2005). While it is conceptually possible to separately estimate producer surplus effects to each of these suppliers, in practice, estimates of demand for and supply of each input to the inputs to broiler production would be needed; however, such estimates do not exist in the literature. As such, we simply report the total change in producer surplus, which includes the changes in economic welfare to all parties involved in the production of broilers, including contractors, integrators, and others.

To implement the model, we need to specify the size of the supply shock, k, which indicates the proportionate increase in marginal cost caused by a switch from fast- to slow-growth breeds; it is the

Table 1. Relative Performance of Slow-Growth Broilers Fed for Fixed Number of Days

Outcome	Slow 1: Ranger Classic	Slow 2: Ranger Gold	Fast 1: Ross 308	Fast 2: Cobb 500
6 weeks				
Days on feed (days/bird)	42	42	42	42
Production (lb/ft^2/year)	40.305	39.054	40.684	41.277
Cost (\$/ft^2/year)	23.154	24.465	19.419	19.195
	(3.678)	(3.645)	(3.642)	(3.617)
Cost (\$/lb)	0.574	0.626	0.477	0.465
	(0.091)	(0.093)	(0.090)	(0.088)
Partial return (\$/ft^2/year)	9.456	7.133	13.497	14.201
	(4.101)	(3.963)	(4.15)	(4.223)
Breakeven premium (\$/lb) relative to best performer	0.118	0.181	0.017	—
	(0.005)	(0.009)	(0.003)	
7 weeks				
Days on feed (days/bird)	49	49	49	49
Production (lb/ft^2/year)	36.328	35.122	36.669	37.329
Cost (\$/ft^2/year)	19.326	20.276	16.636	16.503
	(3.495)	(3.464)	(3.506)	(3.492)
Cost (\$/lb)	0.532	0.577	0.454	0.442
	(0.096)	(0.099)	(0.096)	(0.094)
Partial return (\$/ft^2/year)	10.066	8.141	13.032	13.700
	(3.676)	(3.547)	(3.712)	(3.787)
Breakeven premium (\$/lb) relative to best performer	0.100	0.158	0.018	—
	(0.004)	(0.009)	(0.003)	

Notes: Numbers in parentheses are standard deviations. Means are calculated across 225 monthly observations of input and output prices from January 2000 to September 2018.

vertical shift in the supply curve expressed relative to the initial equilibrium price. Again, interest is in calculating the impact to producers and consumers if the entire industry shifted from fast- to slow-growth broilers. The percentage change in the calculated cost per pound when moving from the average of the two fast-growth breeds to the average of the two slow-growth breeds is used to infer the size of the supply shift.

To implement the model, values also need to be assigned for the other parameters. The values are assigned as follows: $\eta = -0.78$ (Gallet, 2010), $\varepsilon = 0.085$ (Holt and McKenzie, 2003), $\sigma = 0.1$ (Wohlgenant, 1989), $\gamma = -1.5$, $P^0Q^0 = \$53.98$ billion/year (calculated by multiplying per capita consumption, population, and retail prices as reported by the U.S. Department of Agriculture, 2018b,c, averaged for 2013–2017), $w^0x^0 = \$29.67$ billion/year (calculated as the average value of boiler production for 2013–2017 as reported by the U.S. Department of Agriculture, 2018e; see also U.S. Department of Agriculture *Poultry Production and Value Report*, 2018d), $S_d = 0.84$ (the share of 2017 U.S. broiler production going to domestic sources versus exports, as reported

Table 2. Relative Performance of Slow-Growth Broilers at Fixed Final Weight (6 lb broiler)

Outcome	Slow 1: Ranger Classic	Slow 2: Ranger Gold	Fast 1: Ross 308	Fast 2: Cobb 500
Days on feed (days/bird)	54	59	42	41
Production (lb/ft^2/year)	33.934	30.723	40.684	41.922
Cost (\$/ft^2/year)	17.451	16.684	19.419	19.689
	(3.380)	(3.246)	(3.642)	(3.635)
Cost (\$/lb)	0.514	0.543	0.477	0.470
	(0.100)	(0.106)	(0.090)	(0.087)
Partial return (\$/ft^2/year)	10.005	8.174	13.497	14.230
	(3.425)	(3.096)	(4.150)	(4.296)
Breakeven premium (\$/lb) relative to best performer	0.125	0.197	0.018	—
	(0.029)	(0.045)	(0.005)	

Notes: Numbers in parentheses are standard deviations. Means are calculated across 225 monthly observations of input and output prices from January 2000 to September 2018.

by the World Agricultural Outlook Board, 2018), $w^0 x_f^0 = w^0 x^0 (1 - S_d) = \$4.74$ billion/year, and $S = \frac{w^0 x_d^0}{P^0 Q^0} = \frac{w^0 x^0 S_d}{P^0 Q^0} = (\$29.670.84)/\$53.98 = 0.46$.

Results

Table 1 shows economic performance outcomes under the assumption that each broiler breed is fed for a fixed number of days—either 6 weeks (42 days) or 7 weeks (49 days). Total quantity produced per square foot is similar for both slow- and fast-growing breeds. Given the data in Figure 1, this result might appear counter-intuitive. However, note that on day 42, slow-growth broiler breeds weigh 4.4 lb/broiler and 4 lb/broiler, whereas the faster-growing breeds weigh 6.2 lb/broiler and 6.3 lb/broiler. Given that stocking density is defined by the National Chicken Council (2017b) as a maximum of 8.5 lb/ft^2, this implies on day 42 there can be 8.5/4.4 = 1.92 broilers/ft^2 and $8.5/4 = 2.14$ broilers/ft^2 for the two slow-growth breeds but only $8.5/6.2 = 1.37$ broilers/ft^2 and $8.5/6.3 = 1.35$ broilers/ft^2 for the two fast-growth breeds. Thus, in this scenario, there is similar output produced per square foot because there are more slower-growth broilers per square foot than fast-growth broilers when stocking density is defined on a weight basis.

Despite similar quantity produced, Table 1 shows that costs are about \$4 to \$5/ft^2 higher for slow-growth breeds than for fast-growth breeds at 42 days, which falls to a difference of about \$2.70 to \$3.70/ft^2 at 49 days. Production costs range from \$0.10/lb to \$0.16/lb higher (or 27% on average) for the faster than slower-growing breeds at 42 days, falling to \$0.08/lb to \$0.13/lb higher (or 24% on average higher) at 49 days. Net partial returns are \$4.04/ft^2 to \$7.07/ft^2 lower for the two slow-growing breeds relative to the best performing fast-growing breed, Cobb 500 if all broilers are fed for 42 days. The results indicate that the slow-growing breeds would need to obtain \$0.118/lb to \$0.181/lb higher output price premiums to achieve the same net partial return as the Cobb 500 if fed 42 days and \$0.100/lb to \$0.158/lb higher output price premiums if fed 49 days.

Given the data in Figure 1, which show substantial differences in the rate of gain across the different breeds, it is also instructive to compare the different breeds when final weight is used as an end-point (Table 2). Table 2 reports that it takes 54, 59, 42, and 41 days, respectively, for the Ranger Gold, Ranger Classic, Ross 308, and Cobb 500 breeds to reach a live weight of 6 lb. When flocks of each breeds are fed to 6 lb, the total production, on a dress-weight basis, is about

Table 3. Relative Performance of Slow-Growth Broilers at Optimal Days on Feed with Identical Stocking Densities across Breeds

Outcome	Slow 1: Ranger Classic	Slow 2: Ranger Gold	Fast 1: Ross 308	Fast 2: Cobb 500
Days on feed (days/bird)	50.880	50.880	−41.902	41.111
	(4.340)	(4.340)	(3.417)	(3.643)
Production (lb/ft^2/year)	35.516	32.682	40.871	42.001
	(2.162)	(2.141)	(2.216)	(2.344)
Cost ($/ft^2/year)	18.833	18.331	19.744	19.931
	(4.593)	(4.459)	(4.941)	(5.030)
Cost ($/lb)	0.526	0.556	0.479	0.470
	(0.108)	(0.112)	(0.102)	(0.100)
Partial return ($/ft^2/year)	10.203	8.409	13.640	14.384
	(3.704)	(3.411)	(4.281)	(4.419)
Breakeven premium ($/lb) relative to best performer	0.117	0.181	0.018	—
	(0.016)	(0.023)	(0.003)	

Notes: Numbers in parentheses are standard deviations. Means are calculated across 225 monthly observations of input and output prices from January 2000 to September 2018.

41 lb/ft^2/year for the faster-growing breeds versus only about 32 lb/ft^2/year for the slower-growing breeds. Costs of production on a square-foot basis are higher for fast- than for slow-growth chickens, but the higher weights of fast-growth broilers more than offsets the higher cost. Costs of production are \$0.514/lb and \$0.543/lb for the slower-growing breeds compared to \$0.477/lb and \$0.470/lb for the faster-growing breeds. Thus, production costs are about 12% higher per pound for the two slow-growing breeds compared to the best-performing fast-growing breed. Partial returns range from about \$3.49/ft^2/year to \$6.06/ft^2/year higher for the faster- versus slower-growing breeds. The slow-growing breeds would have to obtain \$0.125/lb to \$0.197/lb higher output price premiums to achieve the same partial return as the Cobb 500, whereas the Ross 308 achieves almost exactly the same partial return at the same output price.

Table 3 reports the outcomes when, for each of the 225 price data points, the optimal number of days is chosen for each breed. Table 3 also reports that, across the 225 monthly price observations, the number of days on feed that maximizes partial returns per square foot is higher, at about 51 and 55 days, for the slower-growing breeds than for the 42 and 41 days for the faster-growing breeds. As would be expected, owing to the fact that the outcome is maximized, the average partial returns are higher in Table 3 than in Tables 1 and 2. Net partial returns for slow-growth broilers are \$8.41/ft^2/year to \$10.20/ft^2/year increasing to \$13.64/ft^2/year and \$14.38/ft^2/year for the fastest-growing breeds. Costs of production average \$0.54 for the two slow-growth breeds and \$0.47/lb for the two fast-growth breeds, implying that costs are 14% higher per pound for the slower-growth breeds.

Table 4 considers the outcomes with the optimal number of days is chosen for each breed but where the stocking density is 6 lb/ft^2 for the slow-growth breeds. Stocking density for the two fast-growth breeds is held constant at 8.5 lb/ft^2, and thus the last two columns of Table 4 are identical to the last to columns of Table 3 and are repeated for ease of comparison. Figure 2 shows the associated net partial returns averaged across the 225 price observations for each of the four broiler breeds for broilers fed 0–70 days. As Figure 2 shows (see also Table 4), the optimal days on feed for the two slow-growth breeds are 51 and 55 days, indicating the change in stocking density did not substantially affect feeding times. Although optimal feeding times were not much affected,

Table 4. Relative Performance of Slow-Growth Broilers at Optimal Days on Feed with Breed-Specific Stocking Densities

Outcome	Slow 1: Ranger Classic	Slow 2: Ranger Gold	Fast 1: Ross 308	Fast 2: Cobb 500
Days on feed (days/bird)	50.947	54.560	41.902	41.111
	(4.353)	(4.864)	(3.417)	(3.643)
Production (lb/ft^2/year)	25.048	23.061	40.871	42.001
	(1.527)	(1.516)	(2.216)	(2.344)
Cost ($/ft^2/year)	13.301	12.956	19.744	19.931
	(3.242)	(3.150)	(4.941)	(5.030)
Cost ($/lb)	0.527	0.557	0.479	0.470
	(0.108)	(0.112)	(0.102)	(0.100)
Partial return ($/ft^2/year)	7.178	5.912	13.640	14.384
	(2.613)	(2.406)	(4.281)	(4.419)
Breakeven premium ($/lb) relative to best performer	0.285	0.363	0.018	—
	(0.054)	(0.063)	(0.003)	

Notes: Numbers in parentheses are standard deviations. Means are calculated across 225 monthly observations of input and output prices from January 2000 to September 2018.

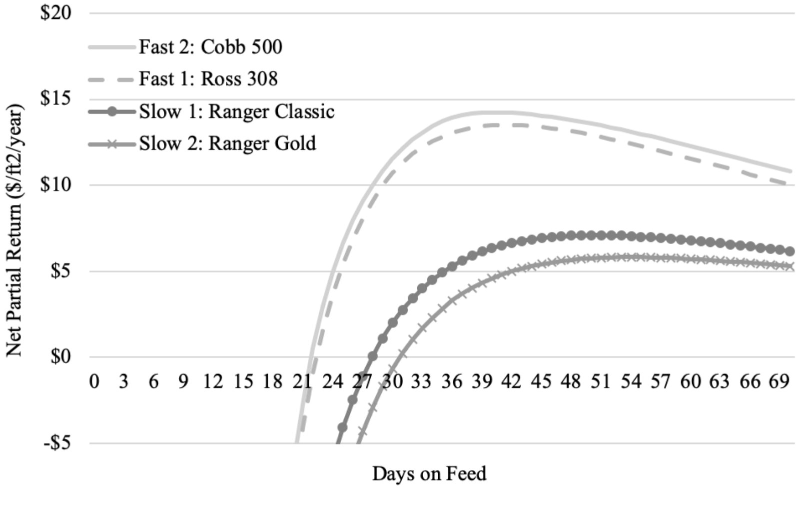

Figure 2. Average Partial Return by Day on Feed for Commercial Slow- and Fast-Growing Broiler Breeds

comparing Tables 3 and 4 shows that total production fell about 10 lb/ft^2 when stocking density was constrained for slow-growth broilers. However, because costs per square foot also fell, costs per pound were not substantially affected. As in Table 4, costs of production average $0.54 for the two slow-growth breeds and $0.47/lb for the two fast-growth breeds, implying costs are 14% higher per pound for the slower-growth breeds. The constraint on stocking density had a substantial effect on profitability. Whereas the breakeven price premiums for slow growth were $0.12/lb and $0.18/lb in Table 3 when stocking density per pound was held constant, these increase to $0.29 and $0.36/lb when stocking density for slow-growth broilers is constrained to 6 lb/ft^2.

Table 5. Market Outcomes Associated with Full Conversion to Slow Growth under Four Scenarios

	Scenario		
Outcome	Feed to Constant No. of Days	Feed to Constant Weight	Optimize Net Returns
Change in marginal cost, k	25%	12%	14%
Change in retail chicken quantity, $\hat{Q}$	−1.14%	−0.55%	−0.64%
Change in retail chicken price, $\hat{P}$	1.46%	0.70%	0.82%
Change in broiler quantity, $\hat{x}$	−1.86%	−0.89%	−1.04%
Change in broiler price, $\hat{w}$	3.16%	1.52%	1.77%
Change in foreign consumer surplus (US$ billions/year)	−$0.15	−$0.07	−$0.08
Change in U.S. consumer surplus (US$ billions/year)	−$0.78	−$0.38	−$0.44
Change in U.S. producer surplus (US$ billions/year)	−$6.42	−$3.10	−$3.61
Increase in U.S. consumer willingness-to-pay for chicken needed to offset U.S. producer losses	22.42%	10.76%	12.55%

Market Impacts

The cost estimates reported in Tables 1–4 are used to specify the size of the supply shock that would result if the entire industry transitioned from fast- to slow-growth broiler breeds. For simplicity in what follows, the effects across the two slow-growth breeds are averaged and are compared to the average of the two faster-growing breeds. For example, in Table 1, at 42 days on feed, the average cost of the two slow-growth breeds is $0.60/lb and the average cost of the two fast-growing breeds is $0.47/lb. This implies that the supply shock is $k = (0.60 - 0.47)/0.47 = 0.27$ for this scenario. Similar calculations imply proportionate increases in marginal cost of 0.24 when all broilers are fed for a fixed 49 days; for simplicity, we utilize $k = 0.25$ for the two scenarios when broilers are fed to a constant number of days on feed. When broilers are fed to a constant weight of 6 lb, the average cost increase when moving from slow- to fast-growth broilers is about 12% per pound. Finally, both Tables 3 and 4 suggest $k = 0.14$ when partial returns are optimized.

Table 5 reports the result from the model outlined in equations (8)–(13). Under the scenario that all broilers are fed for a constant amount of time, converting to slow-growth breeds would increase retail prices by about 1.46% and reduce the amount of retail chicken sold by 1.14%, resulting in losses in producer surplus of $6.42 billion/year and reduced consumer surplus of $0.78 billion/year in the United States and $0.15 billion/year abroad. When partial returns are maximized, the estimated U.S. consumer, foreign consumer, and producer losses are −$0.44 billion/year, −$0.08 billion/year, and $3.61 billion/year, respectively.

The price and welfare changes shown in Table 5 presume that consumer demand for chicken remains unchanged after a conversion to slow growth. However, consumers might prefer slower-growing varieties due to perceived taste, human health benefits, or animal health and welfare benefits (Lusk, 2018), which might also result in an outward demand shift for chicken after such a conversion. The bottom row of Table 5 reports the change in U.S. consumer willingness-to-pay that would be needed to offset producer losses resulting from the higher production costs. These values are identified by finding the demand shift Ît' in equation (8) needed to set $\Delta PS = 0$. The willingness-to-pay increases range from 10.76% when a target end weight is used to 22.42% when a target number of days on feed is used.

Conclusions

This research considered the potential costs of the broiler industry moving from slow- to fast-growth breeds. The results indicate that a conversion to slow growth is likely to increase production costs by about 12%, 14%, and 25% when producers target a fixed weight, optimize partial returns, and target a fixed number of days on feed, respectively. These cost estimates do not include new fixed costs that might be required for additional production facilities. For example, under the most likely scenario, in which net returns are optimized and differential stocking densities are applied to slow- and fast-growth breeds, about 17.45 lb/ft^2/year (or 73%) more chicken on a dressed weight basis is provided by fast- versus slow-growth production systems. Thus, substantially more barn space, or square footage, would be required to produce the same volume of chicken from slow- compared to fast-growth breeds.

In evaluating the economic impacts of slow versus fast-growth breeds, two comparisons are made here, and it is important to distinguish between them given the differences in what these values represent. First, we evaluate changes in production costs and corresponding breakeven price premiums to the producer. These values represent a scenario where an individual producer (assumed to be a price taker) converts to a slow-growth broiler production system. In this case, the wholesale market price for broilers remains unchanged, and thus the breakeven price premium is the additional value ($/lb) that the producer would have to receive to offset the cost increase associated with producing the slower-growing broilers. Breakeven premiums ranged from $0.10/lb to $0.36/lb depending on the scenario considered. Under the most likely scenario, in which net returns are optimized and differential stocking densities are applied to slow- and fast-growth breeds, we calculate that the two slow-growth breeds would need to achieve $0.285/lb and $0.363/lb price premiums to produce the same net partial returns as the highest-performing fast-growth breed. To put these figures in perspective, note that the average wholesale price for broilers over the time period studied here was $0.81/lb, suggesting required breakeven price premiums of about 35% to 45%. The estimated breakeven price premiums are larger than the added costs of slow-growth breeds of about 14%. The difference results from the ability of fast-growth broiler breeds to provide much more output for a given level of costs. Additionally, overall net partial returns are greatly reduced in scenarios where slow-growth broilers are used in conjunction with lower stocking densities given reductions in production, resulting in the higher breakeven premiums.

The second comparison made here uses the relative cost changes for producing slow-growth broilers to inform a partial equilibrium model that estimates the market impacts of an industry-wide shift away from modern fast-growth breeds to slow-growth breeds. That is, the relative cost increase represents the supply shock that would result if the entire industry transitioned from fast- to slow-growth broiler breeds, resulting in estimates of market-level impacts on equilibrium wholesale broiler and retail chicken prices and quantities and, subsequently, producer and consumer surplus. However, losses in producer surplus can be offset if consumers are willing to pay premiums for chicken from slow-growth broilers. Lusk (2018) estimated median consumer willingness-to-pay premiums for chicken breasts of $0.46/lb when chicken packages included brand images and consumers were provided no additional information about slow-growth chicken; this figure increased to $0.54/lb when positive information was provided and fell to $0.26/lb when negative information was provided. At retail chicken breast price of $3.20/lb (the U.S. average in 2017 according to the Bureau of Labor Statistics), a $0.46/lb premium amounts to a 14.3% willingness-to-pay above market prices.

Although a 14.3% willingness-to-pay premium is slightly larger than the estimated 12.55% willingness-to-pay increase needed to offset the added producer costs of an industry-wide conversion to slow-growth in this study, some caveats are in order. First, whether these estimated willingness-to-pay price premiums from surveys would translate into retail behavior is unclear, particularly because the analysis in Lusk (2018) also showed consumers were very unfamiliar with slow-growth chicken in particular and with broiler production in general. Second, prior consumer research focused on consumer demand for chicken breast, the highest-value cut on the chicken carcass; whether willingness-to-pay premiums for slow growth for chicken legs, wings, etc. are as high is uncertain. Regardless, the added cost of slow-growth applies to the entire carcass. Saitone, Sexton, and Sumner (2015) consider cases when consumers are willing to pay premiums for only a part of a carcass with an advertised characteristic. A future area for research is to consider returns and breakeven prices to different broiler cuts from slow- and fast-growing breeds. Finally, there is substantial heterogeneity across consumers (see Lusk, 2018), and average impacts are likely to mask the fact that some consumers would gain and others would lose were retailers to pledge to convert to slow growth.

A final area worth considering for future research relates to the ability of slow- versus fast-growing broiler systems to respond to changes in input and output prices. The partial budgets reported in Tables 1–4 treat prices as exogenous. The equilibrium displacement model (Table 5) relaxes this assumption and considers industry-wide shifts that could affect prices. This equilibrium model assumes a switch to slow growth shifts the supply curve inward due to increased costs of production. It is possible that a move to slow-growth chicken might not only shift the supply curve but also cause the elasticity of supply (the slope of the curve) to change. This would occur, for example, if longer feeding times in slow-growth production systems make such systems less responsive to price changes. Analyzing such effects would require knowledge of how supply elasticity parameters change with a move from fast- to slow-growth broilers.

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