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On the Economic Rationality of Market Participants: The Case of Expectations in the U.S. Pork Market

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This study investigates the nature of price expectations in a competitive market. The approach is illustrated in an application to the U.S. pork market, which exhibits cyclical patterns and biological production lags. Pork price equations are estimated under different expectation regimes. The empirical results suggest the presence of heterogeneous price expectations among market participants. A large proportion of the market (73%) is found to be associated with backward-looking expectations, where future prices are anticipated on the basis of their observed historical patterns.

Key words: business fluctuations, market dynamics, pork market, price expectations

Introduction

An uncertain and changing economic environment is a pervasive characteristic of dynamic resource allocation. This means that economic agents constantly learn about their environment and adjust to its changes. Studying this learning process and its impact on dynamic resource allocation has been the subject of much research. The nature of expectation formation has been the focus of several studies (e.g., Ezekiel; Nerlove; Muth; Nerlove, Grether, and Carvalho; Goodwin and Sheffrin; Eckstein; Orazem and Miranowski; Chow; Holt and Johnson; Nerlove and Fornari), and includes at least four types of expectations: naive, adaptive, quasi-rational, and rational. Naive expectations involve future expected values being set equal to the latest observation of the corresponding variable (Ezekiel). Expectations are adaptive when they are revised over time proportionally to the latest prediction error (Nerlove). Quasi-rational expectations are characterized by predicted values from a time-series model of the corresponding variable (Nerlove, Grether, and Carvalho). Finally, as introduced by Muth, rational expectations are consistent with anticipated supply/demand conditions in the market.

The rational expectations hypothesis has occupied a central place. It states that decision makers make "efficient use" of information, just as they do of other scarce resources. The issue then is to evaluate the exact meaning of "efficient use" of information. If obtaining and processing information is costly, then optimal learning is expected to depend on the net benefits of learning. When some new information is costly or difficult to process, it may not be used by decision makers (e.g., Conlisk). In such situations,

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simple rules of thumb for expectations formation (e.g., naive expectations) could be used. Also, the ability to obtain and process information may vary across individuals. Differences in education or experience could imply different learning rates across individuals, ceteris paribus. Because costs and benefits of information are individual specific, different individuals may have different expectations. At the aggregate level, dynamic resource allocation then would be influenced by the heterogeneity of expectations among decision makers.

The objective of this study is to investigate the nature of expectation formation, with an empirical application to the U.S. pork market. An extensive body of literature has analyzed the functioning of the pork market (e.g., Coase and Fowler; Breimyer; Larson; Jelavich; Harlow; Talpaz; Kaylen; Shonkwiler and Spreen; Hayes and Schmitz; Chavas and Holt). Much of the research has focused on describing and explaining the pork cycle. In some respects, the presence of the pork cycle can be disturbing for economists. If a predictable cycle existed, then producers responding in a counter-cyclical fashion could earn larger than normal profits over time (Hayes and Schmitz). In the presence of predictable price movements, counter-cyclical production response could possibly smooth out market fluctuations, causing the cycle to disappear.

Recent research has shown that rational expectations and efficient decisions do not necessarily imply the absence of economic cycles. In particular, Rosen, and Rosen, Murphy, and Scheinkman have argued that an economic cycle can be fully consistent with the efficient management of an animal population under rational expectations. Yet, the assumption of naive or adaptive expectations (dating back to Coase and Fowler; Ezekiel; and others) has been a basic premise in much of the literature on livestock supply response (e.g., Foster and Burt). Because the dynamics of price expectations by market participants can influence price and market dynamics, the nature of rationality could play a role in explaining the continued existence of economic cycles (e.g., Evans and Ramey; Sargent; Leijonhufvud; Conlisk; Brock and Hommes). This suggests a need to investigate the exact nature of market information used in forming expectations and in making production decisions.

This analysis develops and estimates an econometric model of the pork market. Because of production lags in the pork production process, production decisions are made ahead of marketing decisions. As a result, production decisions are based on expectations about future market conditions. We investigate the nature of expectations within the pork industry, including naive, quasi-rational, and rational expectations.

Under Muth's hypothesis, rational expectations would be forward-looking and based on a full understanding of market pricing. This involves the demand side as well as the supply side of the market. The supply side is dynamic as it involves the management of the hog breeding herd over time. We derive supply dynamics from the economics of animal population management (e.g., Chavas and Klemme; Rosen; Rosen, Murphy, and Scheinkman), and allow for heterogeneous expectations among producers in supply dynamics. We propose an econometric methodology leading to the specification and estimation of a model of price determination and dynamic market allocation. When applied to the U.S. pork market, the methodology provides evidence of heterogeneous expectations among pork producers. We find that a large proportion of the market (73%) is associated with backward-looking expectations, where future prices are anticipated on the basis of their observed historical patterns.

Animal Population Management

Consider a competitive firm managing an animal population. Let b_t denote the size of the breeding herd, as measured by the number of adults at time t. Given a reproduction rate k_t, the number of offspring at time t is denoted by $h_t = k_t b_t$, where k_t is the number of offspring per adult. Assume that the length of a period is defined such that offspring become adults after one period. At time period t, each offspring can face one of three situations: (a) it can be slaughtered for human consumption, (b) it can be kept for breeding, or (c) it can die of natural causes. Let h_{st} denote the number of offspring slaughtered for human consumption, h_{bt} the number of offspring kept for breeding, and h_{dt} the number of offspring dying of natural causes. This implies that:

$$
\begin{aligned}
(1) \qquad h_t = k_t b_t &= h_{st} + h_{bt} + h_{dt}, \\
&= h_{st} + h_{bt} + \delta_{ht} h_t,
\end{aligned}
$$

where $h_{dt} = \delta_{ht} h_t$, with δ_{ht} denoting the death rate of offspring at time t. The evolution of the breeding herd over time is then given by:

$$
\begin{aligned}
(2a) \qquad b_{t+1} - b_t &= h_{bt} - b_{st} - b_{dt}, \\
&= h_{bt} - b_{st} - \delta_{bt} b_t, \\
(2b) \qquad &= (1 - \delta_{ht}) k_t b_t - \delta_{bt} b_t - s_t, \\
&\quad \text{using equation (1),}
\end{aligned}
$$

where b_{st} is the number of adults slaughtered, $b_{dt} = \delta_{bt} b_t$ is the number of adults dying of natural causes, δ_{bt} is the death rate among adults, and $s_t = (h_{st} + b_{st})$ denotes the total number of animals slaughtered at time t. Equation (2a) simply states that the change in the size of the breeding herd from one time period to the next equals the number of offspring added to the breeding herd, minus the number of adults slaughtered, minus the number of adults dying of natural causes.

The management of the animal population is costly. Denote the cost of managing the adult population b_t, the offspring h_t, and the slaughter s_t by $c_t(q_t, b_t, h_t, s_t)$, where q_t represents input prices at time t. Assume that the animals slaughtered at time t (s_t) are sold on a competitive market at a unit price p_t. Then, the firm's net income generated from the management of the animal population at time t is:

$$
(3) \qquad \pi_t = p_t s_t - c_t(q_t, b_t, h_t, s_t).
$$

The firm faces uncertainty about future values of the market price p_t, the death rates δ_{ht} and δ_{bt}, and the productivity factor k_t. These variables are observed at time t, but their future values are treated as random. They are assumed to have some subjective probability distribution reflecting the information available to the decision maker. The evaluation of this uncertainty is discussed in more detail below.

Assume that the manager of the animal population is risk neutral and makes decisions so as to maximize the expected present value of net income over his/her planning horizon.[1] This corresponds to the following optimization problem:

$$\text{Max}\left\{E\left[\sum_{t=0}^{T}(1+r)^{-t}\pi_t\right]: \text{ s.t. equations (1), (2b), and (3)}\right\},$$

where E is the expectation, T is the length of planning horizon, and $(1 + r)^{-1}$ is the discount factor, with r being the discount rate reflecting time preferences. Assuming that the decision maker learns over time, this problem can be alternatively formulated as the following stochastic dynamic programming problem:

$$\text{(4)} \quad \begin{aligned} V_t(b_t) &= \text{Max}\left\{E_t\left[\pi_t + (1+r)^{-1}V_{t+1}(b_{t+1})\right]: \right. \\ &\qquad\qquad \left. \text{s.t. equations (1), (2b), and (3)}\right\}, \\ &= \underset{s_t}{\text{Max}}\left\{E_t\left[p_t s_t - c_t(q_t, b_t, k_t b_t, s_t)\right.\right. \\ &\qquad\qquad \left.\left. + (1+r)^{-1}V_{t+1}[(1-\delta_{ht})k_t b_t + (1-\delta_{bt})b_t - s_t]\right]\right\}, \end{aligned}$$

where $V_t(b_t)$ is the indirect objective function (or value function) conditional on the size of the breeding herd b_t, and E_t is the expectation operator based on the information available at time t. Learning is represented by improvements in the information available to the decision maker from one period to the next. While the realized values of the random variables (p_t, δ_{ht}, δ_{bt}, k_t) become observed at time t, some expectation formation is needed to represent the expected future values of these random variables. This issue is addressed in the next section.

Equation (4) is Bellman's equation of dynamic programming defining recursively the value function $V_t(b_t)$. Under differentiability and assuming interior solutions,[2] the first-order necessary condition for s_t in (4) is:

$$\text{(5)} \quad p_t - \partial c_t/\partial s_t - (1+r)^{-1}E_t[\partial V_{t+1}/\partial b_{t+1}] = 0.$$

From the envelope theorem applied to (4), we have:

$$\text{(6)} \quad \begin{aligned} \partial V_t/\partial b_t &= E_t\left[-\partial c_t/\partial b_t - k_t\partial c_t/\partial h_t\right. \\ &\qquad \left. + (1+r)^{-1}(\partial V_{t+1}/\partial b_{t+1})\left((1-\delta_{ht})k_t + (1-\delta_{bt})\right)\right], \\ &= -\partial c_t/\partial b_t - k_t\partial c_t/\partial h_t \\ &\qquad + \left[E_t(p_t) - \partial c_t/\partial s_t\right]\left[(1-\delta_{ht})k_t + (1-\delta_{bt})\right], \end{aligned}$$

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[1] The assumption of risk neutrality has been commonly made in previous work on dynamic animal economics (e.g., Rosen; Rosen, Murphy, and Scheinkman). Note that it neglects the possible role of risk aversion in dynamic resource allocation. Exploring such issues appears to be a good topic for further research.

[2] Although corner solutions may exist at the micro level, they typically are not observed at the aggregate level. Since our empirical analysis relies on market data, our assumption of "interior solutions" then appears "reasonable." Note that this is consistent with the analysis presented by Rosen and by Rosen, Murphy, and Scheinkman.

using equation (5). Substituting (6) into equation (5) then yields:

$$(7)\qquad (p_t - \partial c_t/\partial s_t) - (1+r)^{-1}E_t\big[-\partial c_{t+1}/\partial b_{t+1} - k_{t+1}\partial c_{t+1}/\partial h_{t+1} + (p_{t+1} - \partial c_{t+1}/\partial s_{t+1}) \times \big((1-\delta_{h,t+1})k_{t+1} + (1-\delta_{b,t+1})\big)\big] = 0.$$

Equation (7) is Euler's equation, showing the dynamics of the animal population under optimal management and competitive market conditions. It gives a dynamic relationship between the current price p_t and the expected next-period market price $E_t(p_{t+1})$. Note that equation (7) involves the discounted expected next-period market value,

$$(1+r)^{-1}E_t\big[(p_{t+1} - \partial c_{t+1}/\partial s_{t+1})\big((1-\delta_{h,t+1})k_{t+1} + (1-\delta_{b,t+1})\big)\big],$$

which is an increasing function of market price p_{t+1} and productivity k_{t+1}, and a decreasing function of marginal slaughter cost $\partial c_{t+1}/\partial s_{t+1}$ and death rates $\delta_{h,t+1}$ and $\delta_{b,t+1}$. Equation (7) can be alternatively written as:

$$p_t = \partial c_t/\partial s_t + (1+r)^{-1}E_t\big[(p_{t+1} - \partial c_{t+1}/\partial s_{t+1})\big((1-\delta_{h,t+1})k_{t+1} + (1-\delta_{b,t+1})\big) - \partial c_{t+1}/\partial b_{t+1} - k_{t+1}\partial c_{t+1}/\partial h_{t+1}\big].$$

This alternative form states that, at the optimum, the current market price p_t equals the marginal slaughter cost $\partial c_t/\partial s_t$, plus the discounted expected next-period market value,

$$(1+r)^{-1}E_t\big[(p_{t+1} - \partial c_{t+1}/\partial s_{t+1})\big((1-\delta_{h,t+1})k_{t+1} + (1-\delta_{b,t+1})\big)\big],$$

minus the discounted expected next-period marginal cost,

$$(1+r)^{-1}E_t\big[\partial c_{t+1}/\partial b_{t+1} + k_{t+1}\partial c_{t+1}/\partial h_{t+1}\big].$$

This characterizes the optimal firm supply conditions taking market prices as given, and shows that production decisions are based in part on expectations about future technology and market prices.

Market Equilibrium and Expectations Formation

In this section, we consider the competitive market equilibrium in an industry composed of the firms managing the animal population. Assuming that the animal product is not storable, the market equilibrium price is determined by the intersection of aggregate supply and aggregate demand. We investigate how expectations of future prices are formed. Three possible expectation regimes are considered: rational expectations (regime 1), quasi-rational expectations (regime 2), and naive expectations (regime 3). We assume that all firms in the industry face the same technology,[3] except for idiosyncratic shocks in the death rates (δ) and birth rates (k) that are firm specific. As a result, at the firm level, we assume that the random variables δ and k are independently distributed of market prices.

At the market level, we focus our attention on aggregate behavior. Let B_t be the aggregate breeding herd, and S_t aggregate slaughter. Then equation (2) suggests the following specification:

$$B_t = (1 - \Delta_{h,t-1})K_{t-1}B_{t-1} + (1 - \Delta_{b,t-1})B_{t-1} - S_{t-1}, \tag{8}$$

where Δ_{ht} is the aggregate death rate for offspring, Δ_{bt} is the aggregate death rate for adults, and $K_t = H_t/B_t$ is aggregate productivity (i.e., average number of offspring per adult) at time t. Equation (8) gives the dynamics of the aggregate breeding herd.

Rational Expectations

Under rational expectations (regime 1), price expectations are consistent with market equilibrium conditions. If each firm in the industry holds rational expectations and uses a similar technology, then under a quadratic cost function $c(\cdot)$, Euler equation (7) applies at the aggregate. Denote the price-dependent demand function by:

$$p_t = f(D_t), \tag{9}$$

where D_t is the aggregate demand for slaughter, and $\partial f/\partial D_t < 0$, corresponding to a downward-sloping demand curve. Let S_t denote the aggregate number of animals slaughtered at time t. Then, in the absence of storage, the market equilibrium condition at time t is $D_t = S_t$, or:

$$p_t = f(S_t). \tag{10}$$

The market equilibrium is then obtained by jointly solving equations (7) (applied at the aggregate), (8), and (10) for slaughter, breeding herd, and market price. Under rational expectations, the expectation operator E_t in (7) is defined to be consistent with the market equilibrium model. This means that price expectations are consistent with the reduced form of the market equilibrium model, i.e., that future prices in (7) can be interpreted as the dependent variables generated by this reduced form. Assume that the econometrician does not have more information than the industry decision makers. Denote by E_{t0} the expectation operator based on the information available to the econometrician at time t. Then equation (7) can be written as the following implicit equation:

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[3] Assuming that all firms face the same technology may appear to be a restrictive assumption. But the investigation of dynamics under heterogeneous technology requires panel data. Basically, without panel data, the effects of heterogeneous technology on market dynamics are not empirically tractable. Unfortunately, panel data on firms over several decades are rarely available. In this context, our assumption of homogeneous technology is motivated in large part by current data limitations. While this does limit the depth of our analysis, we leave the investigation of heterogeneous technology and its effects on market dynamics as a good topic for further research.

(11) $$(p_t - \partial c_t/\partial s_t) - (1+r)^{-1}\big[-\partial c_{t+1}/\partial b_{t+1} - E_t(k_{t+1})\partial c_{t+1}/\partial h_{t+1} + (p_{t+1} - \partial c_{t+1}/\partial s_{t+1}) \times E_t\big((1-\delta_{h,t+1})k_{t+1} + (1-\delta_{b,t+1})\big)\big] = e_{pt},$$

where e_{pt} is an error term satisfying $E_{0t}E_t(e_{pt}) = 0$.

The structural market equilibrium model consists of the breeding equation (8), the demand equation under market clearing (10), and the pricing equation (11) (applied at the aggregate). Given appropriate parametric specifications for the cost function $c(\cdot)$ and for expectations with respect to k_{t+1} and the δ_{t+1}'s, an econometric model is obtained (see below). The associated structural parameters can be consistently estimated. The presence of dependent variables on the right-hand side of the structural equations suggests using an instrumental variable method to deal with simultaneous equation bias. Below, we propose the use of Hansen's generalized method of moments (GMM) as an instrumental variable method (see Hansen; Hansen and Singleton). In principle, the instruments should be chosen from the information set common to the econometrician and industry decision makers. Such instruments would be orthogonal to the error terms, and thus provide consistent parameter estimates. It is known that the choice of instruments is an important issue with GMM, as parameter estimates can be sensitive to competing sets of instruments. This suggests a need to assess the relevance of instruments used in GMM estimation (see below).

Quasi-Rational Expectations

Under quasi-rational expectations (regime 2), prices are anticipated on the basis of their time-series properties as estimated from historical data (Nerlove, Grether, and Carvalho). We assume that expected prices in (7) under quasi-rational expectations are obtained from the prediction of the univariate autoregressive process for the corresponding prices. Let y_t follow the autoregressive process $\{y_t = \beta_{y00} + \beta_{y0}t + \Sigma_{j\geq 1}\beta_{yj}y_{t-j} + e_{yt}\}$, where the β's are parameters and $E_t(e_{yt}) = 0$. Then,

(12) $$E_t(y_{t+1}) = \beta_{y00} + \beta_{y0}(t+1) + \sum_{j\geq 1}\beta_{yj}y_{t+1-j},$$

where y_t is either p_t or q_t. Equation (12) gives expected prices that are consistent with the observed dynamic pattern of prices. When substituted into (7), these expected prices depict the dynamic pricing equations under quasi-rational expectations. Then, equations (7) [applied at the aggregate, and using (12)], (8), and (10) give the market dynamics under quasi-rational expectations. As in the rational expectations case, this system can be estimated econometrically after appropriate parameterization.

Naive Expectations

Next, we consider the case of naive expectations (regime 3). Under naive expectations, producers are assumed to expect the last observed price. This simple expectation rule is the standard assumption in the cobweb model (Ezekiel). With respect to the variable y_t, it implies:

$$E_t(y_{t+j}) = y_t, \quad \text{for } j \geq 1. \tag{13}$$

Note that (13) ignores the dynamic properties of market prices if they depart from a random-walk model. When substituted into (7), these expected prices determine the dynamic pricing conditions under naive expectations. Then, equations (7) [applied at the aggregate, and using (13)], (8), and (10) give the market dynamics under naive expectations. Again, this system can be estimated econometrically after appropriate parameterization.

Heterogeneous Expectations

Finally, we consider the possibility of heterogeneity across firms in obtaining and processing market information. As mentioned, this heterogeneity can be due to differences among firms in access to information or in the cost or ability to process information (e.g., because of differences in the decision maker's education or experience). As a result, heterogeneous expectations can arise within the industry.

We consider the possible presence of three expectation regimes. Denote by $N = \{1, 2, 3\}$ the set of expectation regimes within the industry, with $i \in N$ being the ith group characterized by a given expectation formation. We allow for some firms to exhibit rational expectations (regime 1), others quasi-rational expectations (regime 2), and still others naive expectations (regime 3). Let E_{it} be the expectation operator reflecting the information available to the ith group of firms at time t, $i \in N$.

At time t, denote by b_{it} the size of the breeding herd in the ith group, by h_{it} the number of offspring, and by s_{it} the number of animals slaughtered in the ith group, $i \in N$. Let the cost function for the ith group at time t be $c_{it} = c_t(q_t, b_{it}, h_{it}, s_{it})$, $i \in N$. Then, from (7), the pricing equation for the ith group is:

$$\begin{aligned}(p_t - \partial c_{it}/\partial s_{it}) - (1+r)^{-1}E_{it}\big[&-\partial c_{i,t+1}/\partial b_{i,t+1} - k_{i,t+1}\partial c_{i,t+1}/\partial h_{i,t+1} \\ &+ (p_{t+1} - \partial c_{i,t+1}/\partial s_{i,t+1}) \\ &\times \big((1-\delta_{hi,t+1})k_{i,t+1} + (1-\delta_{bi,t+1})\big)\big] = 0,\end{aligned} \tag{14}$$

where $(\delta_{hit}, \delta_{bit})$ denote the ith group death rates, and k_{it} is the ith group productivity, $i \in N$. Equation (14) involves the expectation operator E_{it} reflecting the information available to the ith group at time t. For each expectation regime i in (14), the specification corresponds to the model discussed above representing the dynamics of prices under the corresponding regime. For example, equation (12) applies in (14) under quasi-rational expectations ($i = 2$), while equation (13) holds under naive expectations ($i = 3$). This illustrates the role of information in dynamic resource allocation. By showing that price expectations can influence pricing, the model implies that observed market dynamics depend on the nature of price expectations from all market participants. In that sense, the observed dynamics of prices can provide an empirical basis to estimate and evaluate the information processed by market participants.

The empirical implementation of the above equations requires addressing the issue of the relevant information set involved in the formation of expectations. Unfortunately, data are rarely available on group-specific information (i.e., b_{it}, s_{it}, h_{it}, etc., $i \in N$). As a result, equation (14) is typically not empirically tractable for each group $i \in N$. Here, we consider the case where data are available only at the aggregate level (i.e., aggregate breeding herd, $B_t = \Sigma_{i\in N} b_{it}$; aggregate slaughter, $S_t = \Sigma_{i\in N} s_{it}$; aggregate number of offspring, $H_t = \Sigma_{i\in N} h_{it}$; etc.). We are interested in developing a methodology that can be empirically tractable in this context.

Such a model should have the following desirable characteristics. It should be consistent with the Euler equation (14) for each group within the industry. It should also include as a special case the situation of homogeneous expectations just discussed. For example, if all firms use a single expectation regime (say the jth regime), then the model should reduce to the Euler equation (14) for the jth group. On that basis, we propose to represent optimal slaughter as a weighted sum of equation (14) across groups:

$$(15)\quad \sum_{i\in N} w_{it} \Big\{(p_t - \partial c_{it}/\partial s_{it}) - (1+r)^{-1}E_{it}\Big[-\partial c_{i,t+1}/\partial b_{i,t+1} - k_{i,t+1}\partial c_{i,t+1}/\partial h_{i,t+1} + (p_{t+1} - \partial c_{i,t+1}/\partial s_{i,t+1}) \times \big((1-\delta_{hi,t+1})k_{i,t+1} + (1-\delta_{bi,t+1})\big)\Big]\Big\} = 0,$$

where w_{it} denotes (nonstochastic) weights for the ith group at time t, with $w_{it} \geq 0, i \in N$, and $\Sigma_{i\in N} w_{it} = 1$. We interpret the weights (w_{it}) as "market shares," where $w_{it} = s_{it}/S_t$. Equation (15) has the desirable characteristics just mentioned. It is implied by the group-specific Euler equations given in (14). If all firms use a single expectation regime (say the jth regime), then $w_{jt} = 1$, and $w_{it} = 0$, for all $i \neq j$, implying that equation (15) reduces to the Euler equation (14) for the jth group. In other words, the general case of heterogeneous expectations given in (15) nests nicely the special case of homogeneous expectations.

The specification for each group i in (15) is given by the specification of the corresponding expectation regime discussed above. For simplicity, we will assume that the cost function $c(\cdot)$ is linear in (b, h, s) so that the marginal costs in (15) can be evaluated independently of the group-level quantities. Note that this is the assumption also made by Rosen, and by Rosen, Murphy, and Scheinkman. Assuming that the weights w_{it} can be parameterized, equation (15) provides a convenient econometric specification that introduces heterogeneous expectations in a manner consistent with within-group rationality (see below).

In order to make equation (15) econometrically tractable, the weights w must be identified. This requires that the three expectation regimes involve different information sets. The distinction between naive expectations and quasi-rational expectations requires that market prices do not follow a random walk. But is the distinction between quasi-rational and rational expectations always meaningful? There are situations where the two can be equivalent. For example, this could occur if all firms exhibit rational expectations, while quasi-rational expectations are generated by the reduced form of the rational expectations model. However, whenever some market participants do not exhibit "full rationality," their effect on price dynamics typically will influence quasi-rational expectations in a way that can differ from "Muth-rationality" (e.g., Brock and Hommes). To the extent that this happens, the distinction among expectation regimes becomes empirically meaningful.

Thus, the structural market equilibrium model under heterogeneous expectations consists of the aggregate breeding equation (8), the aggregate demand equation under market clearing (10), and the price equation (15). As in the case of rational expectations discussed above, the structural parameters can be consistently estimated (provided that they are identified) using an instrumental variable method. Again, we rely on Hansen's GMM estimation method to estimate the parameters. This is illustrated next with an application to the pork market.

Application to the U.S. Pork Market

The pork breeding herd consists of adult females (sows) and males (boars). After a pregnancy period of 114 days, sows produce pigs at a rate of 8–12 pigs per sow per farrowing. The pigs are nursed for 3–5 weeks, then weaned. This allows each sow to produce about two farrowings a year. Pigs can be fed until 6–7 months old, and marketed at a weight of 180–250 pounds. Or they can join the breeding herd, with a first mating around eight months of age. Adult pigs become fully grown at 1.5–2 years of age, and can live up to 9–15 years.

Aggregate data were obtained from the U.S. Department of Agriculture (USDA) on the U.S. pork market between 1960 and 1996. The data include the size of the breeding herd (B_t), pig crop (H_t), slaughter (S_t), hog price received by farmers in the U.S. (p_t), as well as corn price received by farmers (q_t), as published annually in *Agricultural Statistics* (USDA). Corn price represents input cost, as corn is the most important production input. All prices (p_t, q_t) are measured as real prices, deflated by the consumer price index (as reported by the U.S. Department of Labor, Bureau of Labor Statistics). The analysis relies on annual data.[4] In this context, the U.S. pork market matches well the model developed in our earlier sections. First, the assumption made that offspring become adults after one year is nearly met. Second, meat production is the only final output obtained from pork (at slaughter).

Based on the model developed in previous sections, we propose the following model specification. We specify the aggregate demand function (10) in linear form:

$$p_t = d_0 + d_1 S_t + d_2 t + e_{dt}, \tag{16}$$

where (d_0, d_1, d_2) are demand parameters, and e_{dt} is an error term with mean zero and finite variance. Also, let the aggregate death rates be $\Delta_{ht} = a_0 + a_1 t + e_{aht}$ for offspring, and $\Delta_{bt} = a_0 + a_1 t + e_{abt}$ for adults, where (a_0, a_1) are parameters, and e_{aht} and e_{abt} are

[4] Using quarterly data in our analysis also was considered. We proceeded with annual data for two reasons. First, it simplified the analysis. Second, this avoids the issue of the changing seasonality of pork production during the sample period. The handling of nonstationary seasonality creates significant challenges to the examination of dynamic market analysis. Addressing such challenges appears to be a good topic for further research.

random variables with mean zero.[5] This represents the death rates as being stochastic with a linear trend t. If the slope coefficient is negative ($a_1 < 0$), the effect of the linear trend would represent improved management contributing to lower death rates over time.

Now, the dynamics of the aggregate breeding herd given in (8) can be written as:

$$B_t = \big(1 - a_0 - a_1(t-1)\big)(1 + K_{t-1})B_{t-1} - S_{t-1} + e_{bt}, \tag{17a}$$

where

$$K_t = H_t/B_t = \gamma_0 + \gamma_1 t + e_{kt}, \tag{17b}$$

such that γ_0 and γ_1 are parameters, and $\{e_{bt} = (-K_{t-1}B_{t-1}e_{ah,t-1} - B_{t-1}e_{ab,t-1})\}$ and e_{kt} are error terms distributed with mean zero and finite variance. Equation (17b) shows the productivity factor K_t as stochastic with a linear trend t. If it has a positive effect ($\gamma_1 > 0$), the linear trend would reflect technological progress in the U.S. pork industry, contributing to improved productivity over time.

We assume that the random variables k_{it} (the birth rate), δ_{hit}, and δ_{bit} (the death rates) are independently distributed, serially uncorrelated, and satisfy $E_{0t}E_{it}(k_{i,t+1}) = E_{0t}(K_{t+1})$, $E_{0t}E_{it}(\delta_{hi,t+1}) = E_{0t}(\Delta_{h,t+1})$, and $E_{0t}E_{it}(\delta_{bi,t+1}) = E_{0t}(\Delta_{b,t+1})$, for all t and all $i \in N$, where E_{0t} is the expectation based on the information available to the econometrician at time t. This can be interpreted to mean that, in the absence of disaggregate data, the best the investigator can do is to estimate individual productivity index and death rates by their corresponding aggregate measure. From equations (17a) and (17b), this implies that $E_{0t}E_{it}(k_{i,t+1}) = E_{0t}(K_{t+1}) = \gamma_0 + \gamma_1(t+1)$, and $E_{0t}E_{it}(\delta_{hi,t+1}) = E_{0t}E_{it}(\delta_{bi,t+1}) = E_{0t}(\Delta_{t+1}) = a_0 + a_1(t+1)$. These relationships are substituted in the dynamic pricing equations when the model is estimated econometrically. Also, let the cost function $c_t(q_t, b_t, k_t b_t, s_t)$ be specified as $c_t(\cdot) = c_{00}(q_t, t) + (c_0 + c_1 q_t + c_2 t)b_t$, where the c's are parameters to be estimated. This specification ignores slaughter cost; such costs are relatively small and are neglected in our analysis.

Before estimating our structural model under different expectation regimes, we investigated the dynamic properties of market prices. Autoregressive models of pork price (p_t) and corn price (q_t) were specified and estimated. The resulting estimates are used below to represent quasi-rational expectations [as given in equation (12)].

The following pork price equation was estimated (with standard errors in parentheses below the parameter estimates):

$$\begin{aligned} p_t = \underset{(3.9669)}{6.9515} - \underset{(0.0571)}{0.0996t} + \underset{(0.1588)}{0.6318p_{t-1}} - \underset{(0.1876)}{0.1524p_{t-2}} + \underset{(0.1613)}{0.2927p_{t-3}} \\ R^2 = 0.7032. \end{aligned} \tag{18}$$

Several diagnostic tests were performed. The Godfrey test for serial correlation of the residual indicated no statistical evidence of serial correlation (with a p-value of 0.5527).

[5] This specification assumes that the *average* aggregate death rate is the same for offspring and adults. This assumption appears restrictive. It was made after attempts to estimate the two death rates separately failed to give reliable and credible results.

The Ramsey RESET test of functional form failed to uncover evidence of inappropriate functional form (with a p-value of 0.6405). The Lagrange multiplier test of the regression of the squared residuals on the squared predicted values gave no statistical evidence of heteroskedasticity (with a p-value of 0.2020). Finally, a Chow test for parameter stability had a p-value of 0.0728. Using a 5% significance level, this suggests no strong statistical evidence of structural change during the estimation period.

The negative coefficient on the time trend t in (18) reflects a decrease in the real price of pork during the sample period. The roots of the estimated difference equation (18) were evaluated. There are one real root and two complex roots. The dominant root is real: 0.8544. The complex roots have a modulus of 0.5853 and are associated with cyclical patterns. This is consistent with previous literature establishing the existence of a pork cycle (e.g., Talpaz; Kaylen; Hayes and Schmitz; Chavas and Holt). Equation (18) suggests that naive price expectations would fail to capture some important aspects of pork market dynamics.

The following corn price equation was estimated (with standard errors in parentheses below the parameter estimates):

$$\begin{array}{lcccc} q_t = & 0.6111 & - \; 0.0077t & + \; 0.9842q_{t-1} & - \; 0.3480q_{t-2} \\ & (0.2230) & (0.0036) & (0.1637) & (0.1629) \end{array} \tag{19}$$

$$R^2 = 0.7792.$$

Used as a diagnostic test, the Godfrey test for serial correlation of the residual showed no statistical evidence of serial correlation (with a p-value of 0.3812). The Ramsey RESET test of functional form did not find evidence of inappropriate functional form (with a p-value of 0.6405). The Lagrange multiplier test of the regression of the squared residuals on the squared predicted values gave no strong evidence of heteroskedasticity (with a p-value of 0.3058). Finally, a Chow test of parameter stability had a p-value of 0.1472, indicating no statistical evidence of structural change.

The negative coefficient on the time trend t in (19) reflects a decrease in the real price of corn during the sample period. The roots of the estimated difference equation (19) were evaluated. There are two complex roots, with a modulus of 0.5899. Again, equation (19) suggests that naive price expectations would fail to capture some important aspects of corn market dynamics.

We then estimated the structural models discussed in the previous section. First, we consider three models representing the scenarios discussed earlier: (*a*) rational expectations; (*b*) quasi-rational expectations [as given by (12), using the estimates of the autoregressive processes (18) and (19)]; and (*c*) naive expectations [as given by (13)]. This latter scenario is the standard assumption made in the cobweb model (Ezekiel). The parameters of these three models were estimated for the U.S. pork market based on annual data for 1960–96, using the generalized method of moments (GMM) proposed by Hansen. The analysis assumes that the discount rate r is set equal to 0.05.[6] The chosen instruments were the one-period lagged variables for breeding herd B_{t-1}, slaughter S_{t-1}, productivity K_{t-1}, pork price p_{t-1}, corn price q_{t-1}, and a time trend t. The variance-covariance matrix of the parameters was robustly estimated using the Newey-

[6] The results presented below were found to be fairly insensitive to the choice of the discount rate r.

West estimator, correcting for heteroskedasticity and serial correlation with one period lag. Under a set of regularity conditions, the resulting parameter estimates can be shown to be consistent and asymptotically normal (Hansen).

For regime 1 (rational expectations) and regime 3 (naive expectations), the model is estimated in one step. However, for regime 2 (quasi-rational expectations), it proceeds in two steps. The first step involves estimating the autoregressive processes for hog price and corn price [i.e., equations (18) and (19)]. In a second step, such estimates are used to generate expected prices according to (12), which are substituted into the dynamic pricing equation. The structural model is then estimated by GMM, yielding consistent parameter estimates. In this case, the calculation of the standard errors is adjusted to correct for the fact that the estimated expected prices were obtained from a stochastic equation. The estimation results are presented in table 1.

The validity of the econometric specification was first assessed using the Hansen test on the overidentification restrictions generated by the instruments. For each expectation model, the Hansen test does not give statistical evidence against the orthogonality restrictions between the overidentifying instruments and the error terms (see table 1). This suggests that the model specification and the choice of the instruments appear appropriate.

All the estimated coefficients reported in table 1 have the expected sign, and most are significantly different from zero. Given $t = 1$ in 1945, the parameters a_0 and a_1 in equation (17a) show that the average annual death rate has significantly declined from about 8% in the 1960s to about 3% in the 1990s. This reflects improved management practices. The parameters γ_0 and γ_1 in equation (17b) indicate that productivity has increased significantly over time—the average number of offspring per adult per year has gone from 6–7 in the 1960s to 13–14 in the 1990s. The parameters d_0, d_1, and d_2 in the demand equation (16) show a downward-sloping demand function ($d_1 < 0$). The associated demand elasticity evaluated at sample means is about –0.34. This indicates an inelastic demand for pork. This inelastic demand is broadly consistent with previous empirical pork demand estimates.

The parameter estimates for the a's, γ's, and d's are fairly similar across expectation regimes (see table 1). As expected, the cost parameters c_0, c_1, and c_2 show that corn price (through its positive effect on feed cost) tends to increase the marginal cost of holding animals. However, the estimates of c_1 vary substantially across regimes—from 220 in regime 1, to 157 in regime 2, and 140 in regime 3. This suggests that each expectation regime has different implications for dynamic pricing.

Next, we consider the case of heterogeneous expectations, allowing for the simultaneous presence of three expectation regimes: rational expectations ($i = 1$), quasi-rational expectations ($i = 2$), and naive expectations ($i = 3$). This is represented by the pricing equation (15), and is simply a weighted sum of the specifications discussed above under the three expectation regimes. As noted earlier, we interpret the weights w_{it} as "market shares" for the ith group. Also, we assume that $w_{it} = w_i$, i.e., that the proportion of decision makers in each expectation regime is constant over time. This convenient assumption can appear somewhat restrictive; it is imposed mostly to improve the empirical tractability of the model. We thus treat the w_i's in (15) as parameters to be estimated. Such estimation provides a basis for investigating empirically the heterogeneity of expectations among market participants in the pork industry.

Table 1. Parameter Estimates Under Each Expectation Regime

Parameter	Rational Expectation ($i = 1$)	Quasi-Rational Expectation ($i = 2$)	Naive Expectation ($i = 3$)
a_0	0.0949*	0.0967*	0.1019*
	(0.0087)	(0.0107)	(0.0098)
a_1	-0.0012*	-0.0012*	-0.0013*
	(0.0002)	(0.0003)	(0.0003)
γ_0	6.3590*	6.3218*	6.3152*
	(0.0895)	(0.0869)	(0.0866)
γ_1	0.1494*	0.1507*	0.1504*
	(0.0038)	(0.0038)	(0.0034)
d_0	70.3966*	69.1173*	66.8208*
	(2.2530)	(1.9942)	(2.0451)
d_1	-0.5675*	-0.5517*	-0.5270*
	(0.0316)	(0.0290)	(0.0298)
	[-0.3574][a]	[-0.3474][a]	[-0.3319][a]
d_2	-0.1452	-0.1499*	-0.1434
	(0.0308)	(0.0312)	(0.0317)
c_0	-166.4554*	-58.3242	-35.6396
	(40.7611)	(40.4799)	(21.6010)
c_1	220.8117*	157.6548*	140.9334*
	(21.4491)	(23.1108)	(9.6919)
c_2	3.7553*	2.3648*	2.1367*
	(0.6457)	(0.5850)	(0.3669)
Minimum Distance	16.9231	16.7690	16.6207
Hansen Test	χ^2 (18)	χ^2 (18)	χ^2 (18)
p-Value	0.5284	0.5390	0.5493
Standard Error of the Error Terms:			
Equation (16)	2.6549	2.6549	2.6197
Equation (17a)	0.0313	0.0313	0.0310
Equation (17b)	0.6204	0.6204	0.6120
Pricing Equation	35.3156	30.2028	31.3400

Notes: An asterisk (*) denotes that the corresponding parameter is significantly different from zero at the 5% level. Numbers in parentheses are asymptotic standard errors.

[a] Numbers in brackets are demand elasticities evaluated at mean values.

Again, the parameters of the heterogeneous expectation model were estimated using the Hansen GMM method. And again, the analysis assumes that the discount rate is $r = 0.05$. The chosen instruments were the same as above. The variance-covariance matrix was robustly estimated using the Newey-West estimator correcting for heteroskedasticity and serial correlation with a one-period lag. As in the case of regime 2

Table 2. Parameter Estimates for the Heterogeneous Expectations Model

Parameter	Parameter Estimate	Parameter	Parameter Estimate
a_0	0.0968* (0.0091)	c_0	-153.3961 (317.3765)
a_1	-0.0012* (0.0002)	c_1	213.8627 (183.2473)
γ_0	6.3423* (0.0935)	c_2	3.5435 (4.2547)
γ_1	0.1507* (0.0039)	w_1	0.1950 (0.1027)
d_0	69.8765* (2.4553)	w_2	0.7333* (0.3637)
d_1	-0.5637* (0.0340)	w_3	0.0717 (0.3191)
d_2	-0.1429* (0.0315)		

Minimum Distance	15.9312
Hansen Test	χ^2 (16)
p-Value	0.4578
Standard Error of the Error Terms:	
Equation (16)	2.6549
Equation (17a)	0.0313
Equation (17b)	0.6204
Pricing Equation	26.6059

Notes: An asterisk (*) denotes that the corresponding parameter is significantly different from zero at the 5% level. Numbers in parentheses are asymptotic standard errors.

discussed above, the estimation incorporates two steps. The first step involves estimating autoregressive processes for hog price and corn price [equations (18) and (19)]. Under the quasi-rational expectation regime (i = 2), this is used to generate expected prices according to (12), which are then substituted into the dynamic pricing equation. The structural model is then estimated by GMM, yielding consistent parameter estimates. The calculation of the standard errors is adjusted to correct for the fact that the quasi-rational expected prices were obtained from a stochastic equation. The resulting estimates are presented in table 2.

The validity of the econometric specification was assessed using the Hansen test of overidentifying restrictions in GMM estimation. The Hansen test does not give statistical evidence against the orthogonality restrictions between the overidentifying instruments and the error terms (see table 2). This suggests that the model specification and the choice of the instruments appear appropriate.

All the estimated coefficients reported in table 2 have the expected sign, and most are significantly different from zero. The parameters a, γ, and d are similar to those reported in table 1. Again, the cost parameters (c) suggest that feed cost tends to increase the marginal cost of holding animals. Finally, the estimated market share parameters (w) provide useful information on the heterogeneity of expectations. They show that the percentages of farmers exhibiting rational expectations (w_1), quasi-rational expectations (w_2), and naive expectations (w_3) are, respectively, 19.5%, 73.3%, and 7.2%. Note the standard error of w_3 is somewhat large, indicating that the estimate of w_3 is not significantly different from zero. However, the proportion of market participants exhibiting quasi-rational expectations ($w_2 = 0.733$) is significantly different from zero at the 5% level. And the proportion of market participants exhibiting either rational expectation ($w_1 = 0.195$) or naive expectation ($w_3 = 0.072$) is significantly different from one.

These results provide statistical evidence of heterogeneous expectations in the U.S. pork market. They suggest that not all market participants have similar expectation formation. The findings also indicate that a minority of pork farmers either may behave naively ($w_3 = 0.072$) or are fully Muth-rational ($w_1 = 0.195$). The econometric evidence shows that the largest proportion of pork production is associated with quasi-rational expectation ($w_2 = 0.733$). This suggests that the majority of U.S. pork producers (73.3%) understand how pork prices have evolved historically, but their decisions do not fully take into account the dynamics of supply/demand conditions in the pork market.

Implications and Conclusions

We have examined the nature of price expectations in a competitive market. The approach applied to the U.S. pork market indicates the presence of heterogeneous expectations among pork producers. Our findings show that 19.5% of the pork market is characterized by forward-looking price expectations formed according to Muth's rational expectations hypothesis. Also, a small proportion of pork production (7.2%) involves "naive expectations," where production decisions depend only on the most recently observed market prices (as assumed in the cobweb model; see Ezekiel). Finally, a majority of pork production (73.3%) comes from farmers using quasi-rational expectations and anticipating future prices on the basis of observed historical patterns.

These results can be interpreted in terms of the costs and benefits to market participants of obtaining and processing information about market prices. Indeed, while we did not measure such costs and benefits directly, our findings shed some indirect light on their relative magnitude.

Consider that market participants would decide to obtain price information only if they perceive receiving positive *net* benefit from it. The finding that 73.3% of pork production is carried out by farmers exhibiting quasi-rational expectations suggests that most producers perceive positive *net* benefit anticipating future prices from their observed past behavior. This can be interpreted to mean that the *gross* benefit from understanding the time-series properties of historical prices is larger than the cost of obtaining the associated information. But for these producers, why are "backward-looking" quasi-rational expectations preferred to the "forward-looking" rational expectations? By not being "Muth-rational," quasi-rational expectations are neglecting some relevant information about market price determination (e.g., the characteristics of supply and demand conditions). This means that the *gross* benefit of rational expectations is expected to be larger than the *gross* benefit of quasi-rational expectations for a particular producer. It follows that, compared to rational expectations, the *net* benefit of quasi-rational expectations can be higher *only if* the associated information cost is lower. Our results suggest that, for farmers engaged in 73.3% of pork production, the *net* benefit of quasi-rational expectations is larger than that for rational expectations. This can be interpreted as indirect evidence that the cost of having rational expectations is significantly higher than the cost of having quasi-rational expectations. This difference in information cost appears to have an important influence on resource allocation. More specifically, for the farmers using quasi-rational expectations, the high cost of obtaining and processing rational expectations apparently leads them to choose use of less than full information, thus generating "boundedly rational" behavior.

This finding has several implications. First, our analysis presents indirect evidence that the cost of obtaining and processing market information is positive and significant. Second, this cost can provide incentives for decision makers to save on information cost by exhibiting bounded rationality, which influences prices and the dynamics of markets. At this point, more research is needed to study the linkages across bounded rationality, expectation formation, and the nature of market cycles. Third, we found empirical evidence of heterogeneity in expectations in the U.S. pork market. This means that the ability to obtain and process information varies significantly among market participants. Further research is needed to investigate this heterogeneity and its effects on market dynamics. Finally, the relative importance of backward-looking expectations indicates the possibility of significant dynamic allocative inefficiency in the pork market. Is it possible to improve human capital so as to reduce information cost and increase the quality of expectation formation? Given our finding that only 19.5% of the pork market is associated with "Muth-rationality," there appear to be good prospects to improve the "market intelligence" of industry decision makers, leading to better use of information and improved dynamic allocative efficiency. More research is needed on this topic.

In concluding, it is worthwhile to point out some limitations of our analysis. For example, we assumed that all decision makers are risk neutral. Although such an assumption has been commonly made in recent research on market dynamics (e.g., Rosen; Rosen, Murphy, and Scheinkman), it neglects the possible role of risk aversion. Investigating the effect of risk aversion on price dynamics is a good topic for future research. Also, the issue of structural change is potentially important (e.g., Shonkwiler and Spreen). Besides technical progress, this can involve recent changes in the structure of pork production as well as changes in the "market intelligence" of pork market participants. As suggested by Brock and Hommes, it could be that the nature of price expectations changes in different phases of the pork cycle. Further research is needed to investigate such issues.

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