

A Nonlinear Model of Information and Coordination in Hog Production:
Testing the Coasian-Fowlerian Dynamic Hypotheses[†]

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Abstract

The objective of this paper is to report on the development of a new nonlinear and dynamic synthesis simulation model capable of reproducing Coase and Fowler's structural findings of the 1935-1940 paper series about the pig-cycle. The 'explanation' expounded by Coase and Fowler follows a well-integrated economic logic and an exemplary focus on economic structure that provides economic insight to foster our understanding of commodity cycles. The model was built using structural descriptions of the industry, technical parameters, assumptions and data available in the original paper series. The simulations results replicated all the findings under the alternative hypotheses ('static price expectation' and time-based price expectation') derived from Coase and Fowler's findings. Implications for information and coordination are discussed.

Key Words: cycle, coordination, uncertainty, hog production.

Introduction

Price oscillations and production cycles in hogs (and other livestock) have intrigued economists and preoccupied policy makers around the world for decades. The 'cobweb theorem' remains the traditional textbook reference but recent contributions include vector autoregression (Kaylen, 1988), supply demographics (Rosen *et al.*, 1989), countercyclical production response (Hayes and Schmitz, 1987) and chaos (Chavas and Holt, 1991; Streips, 1995) models that have broadened our understanding of the phenomenon.

Coase's series of papers on the 'pig-cycle', co-authored with R.F. Fowler, and applied to pig production in Great Britain, was launched as a 'critique' of the cobweb theorem and grew over the 1935 to 1940 period into an 'explanation' for the pig-cycle (Coase and Fowler, 1935a, 1935b, 1937, and 1940). With limited 'statistical' means, Coase and Fowler applied a broad set of economic concepts by synthesizing several nonlinear micro and macroeconomic linkages. These linkages included: (a) producers' investments in breeding herds, (b) implications of the inelastic demand for pigs and pig products, (c) producers' supply responses, (d) pork-pig and bacon-pig producers price expectations, (e) asynchronous price incentive mechanisms across the production channel, (f) information transmission and (g) biological production time delays. This paper posits the 'explanation' expounded by Coase and Fowler follows a well-integrated economic logic and an exemplary focus on economic structure that provides economic insight to foster our understanding of commodity cycles.

In particular, their investigation uncovered that the application of the cobweb theorem resulted in a cycle of two years, rather than the observed 'four' years. Their results also suggested that the industry exhibited short-term disequilibrium around "a correct trend," in the long-run. Coase and Fowler posited that the lack of market information - that brought asynchronous pig breeding and finishing production responses combined with production time delays that exacerbated the presence of short-run supra and below 'normal' profit margins after a price change across

production activities - were influencing the behavior of the cycle. Given the inelastic demand for pigs and pig products, the difficulty for producers to precisely predict the industry's supply response and to coordinate production in the short-run with demand perpetuated hog inventory oscillations over time.

To date, the economic literature has reported no efforts to unify and synthesize within a single model a Coasian-Fowlerian 'critique' and 'explanation'. The objective of this paper is to report on the development of a new nonlinear and dynamic monthly simulation model capable of reproducing Coase and Fowler's structural findings of the 1935-1940 paper series. The model was built using structural descriptions of the industry, technical parameters, assumptions and data available in the original papers.

This paper offers several contributions. On the substantive front, issues raised by Coase and Fowler relate to asynchronous effects that a lack of market information has on the price incentive mechanism in production - a key complicating factor of market coordination and a central theme in their papers. The issues characterized by the proposed model are timely given current pressures in U.S. hog production leading to numerous innovative vertical and horizontal coordination mechanisms (Cloutier and Sonka, 1998) and the increased price-sensitivity to production swings induced by the recent increased industry dependence on export markets (Doanes Agricultural Report, 1998).

Computationally, the proposed model takes advantage of dynamic synthesis (Porter, 1969), a quantitative method also known as system dynamics, widely used in electrical engineering and in biological sciences that is becoming a standard computational method to model system feedback in strategic management and economics (Morecroft and Sterman, 1994; Rowley and Cloutier, 1997; Ruth and Hannon, 1997).

Coase and Fowler on the Economic Coordination of Functions and Information

In 1935, Coase and Fowler (1935a) presented an appraisal of the Report of the Reorganisation Commission for Pigs and Pig Products (RCPPP) (Cohen, 1934; Ministry of Agriculture and Fisheries, 1932). This report presented an analysis and policy recommendations based on the behavioral assumption of the cobweb theorem and the peculiarities of British pig and bacon production in 1920s and 1930s. [See Ezekiel, 1927a, 1927b, 1938; and Nerlove 1958, for the classic mathematical reference on the cobweb theorem.] The RCPMP described observed four-year cycles and made policy recommendations to the Pigs and Bacon Marketing Boards. The objective of these policy recommendations was to dampen oscillatory production cycles as a means to address the unstable sources of farmers' profit margins.

Coase and Fowler, challenging the theoretical foundation used by the RCPMP, concluded that assumptions of the cobweb theorem were too limiting to account for the complex oscillatory behavior of the pig-cycle (Coase and Fowler 1935a). They questioned the presumed adjustment mechanism of demand and supply determination implied by the cobweb theorem that assumes producers accurately predict demand and supply conditions, instantaneously implement all necessary adjustments, while market conditions remain constant from the time of production decision to the time of marketing. In subsequent elaborations, they presented alternative explanations and measures of producers price expectation (Coase and Fowler 1937), provided additional details on the measurement of producers' elasticity of expectations (Coase and Fowler 1940) and showed that if the cobweb theorem were applied, it would predict a price cycle of about half the observed frequency of forty-one months, while their proposed 'statistical technique' approximated observed economic phenomena more consistently.

For Coase and Fowler the problem of the pig-cycle is one for producers to make accurate short-term predictions about demand and supply conditions in the market and to implement the necessary adjustments in order to operate at profitable levels. Besides seasonal variations in market

conditions, the regularity of the price oscillations suggested to Coase and Fowler the presence of endogenous factors responsible for this market behavior. "There would be a pig-cycle irrespective of variations in costs, but since these costs do vary the pig-cycle is enhanced" (Coase and Fowler, 1935a:144) regardless whether farmers expand or contract production depending on short-term market conditions.

Coase and Fowler's results led to five other interrelated observations that together undermined the applicability of the cobweb theorem. First, they emphasized that the industry was to a large extent specialized along the functions of breeding and of fattening. Breeders produced store-pigs as inputs for feeders. There was also a greater variability in the profit of feeders which was dependent on factor prices of feedstuffs, store-pigs and on the market price for bacon-pigs. If the price for store-pigs was not increasing as fast as the price for bacon-pigs, even if feedstuffs prices remained constant, the profitability of feeders would fluctuate more than the profitability of breeders. The profit margin of feeders was also affected to a greater extent by fluctuations in feedstuffs prices because of the greater reliance on this input as pigs grow in size. In short, breeders cared about the price received for store-pigs and feeders were concerned about the price received for bacon-pigs. In addition, feeders were subject to variability in both store-pig and feedstuffs prices.

Second, the computation of separate profit margins for feeders and breeders uncovered a nine-month time delay between a direction change in the profit margins of feeders and a direction change in the profits of breeders. This observation suggested that an increase in breeding is not induced by a change in the feedstuffs/bacon-pig price ratio at the industry level, but by a change in the demand for store-pigs at the fattening level. The finding that the profit margin of breeders lagged by nine months changes in the feeder margin is consistent with an observed twenty-one month time delay between a direction change in the feedstuffs/bacon-pig price ratio and a change in

the pig population in Great Britain (Murray, 1933), twelve months of which account for the time it takes from breeding to fattening.

Third, Coase and Fowler (1935a) indicated that if assumptions of the theorem held and producers have to try to determine feedstuffs and bacon-pig prices over time, that is, producers adjust immediately to changing prices which they don't expect to vary during production, the cycle would repeat itself within two years, rather than the forty-one month frequency observed from price series.

Fourth, they pointed out, there was clearly a misalignment in the price incentive mechanism in time between breeders and feeders for store-pig: "if store-pigs prices change at the same time as bacon-pigs prices, then the 'profits' margin of feeders will start to decline when the rate of increase of bacon-pig prices becomes less than the rate of increase of store-pig prices five months earlier" (Coase and Fowler (1935a). (Note the fattening phase takes five months.) They submitted that if the uncertainty of the change in bacon-pig price direction could be eliminated, the price incentive mechanism for store-pigs could be adjusted to coordinate breeding levels that reflect forward adjustments in the profit margin for feeding. That is, in order to stabilize profit margins, they point to the need to align prices by improving information transmission of breeders' store-pig price incentives with actual economic levels for feeders. In reality, feeders could not predict very well the demand for bacon and the supply elasticity of the industry, that is, when bacon-pig price will reach a peak. In the meantime it appears that they kept bidding prices up for store-pigs. The fact remained, however, that higher prices for store-pigs send an incentive to breeders to increase the breeding sow population during a period of nine months following a change in the direction of feeders' margins. In summary, the change in the bacon-pig fattening population occurred with a time delay of twenty-one months, although the incentive is received by breeders five months after a change in the direction of feeders' profit margins, which then creates a nine months lag. By this time feeders oversupply the market with bacon-pigs and prices collapse, leaving them with below normal

profit margins. An increase in demand for bacon-pig products following a reduction in the supply of bacon-pig after another twenty-one month period restarts the cycle again. In their analysis these economic results were corroborated with facts about the industry behavior.

A Nonlinear Model of Information and Coordination

Here, we briefly outline the structure of the model, its parameters, and the key simulation results. The simulations provide a test of the working hypotheses derived from Coase and Fowler's findings. The initial paper by Coase and Fowler (1935a) was presented as a 'critique' of the cobweb theorem. The set of results obtained concerning the inapplicability of the cobweb theorem is used to examine the 'static price expectation hypothesis'. The 'time-based price expectation hypothesis' refers to the model specification that examines the set of results summarized in the 'explanation' (Coase and Fowler, 1937) and that provided additional support for the first, second and fourth observations of the previous section¹.

*Model Overview*²

Figure 1 is a representation of the model³. The figure shows that the initial production stage is the state variable gestation that fluctuates by inception rate. The gestation period is of four months. The parameter in the model used to represent litter size is 3.5 piglets per month. The initial breeding herd is the number of pigs set aside for breeding. The initial breeding herd in the model is arbitrarily set to six⁴. Two-thirds of the breeding herd is assumed to be female. The breeding time of

¹ The 'explanation' concentrates mostly on the market for porker-pig rather than the one of bacon-pig (which are heavier hogs.) The simulations conducted to examine both hypotheses are based on the production structure for the bacon-pig market. Coase and Fowler (1937) indicate that the porker-pig analysis provides essentially the same structural insights. Work is continuing to include the porker-pig market interface and investment in breeding.

² Due to space limitation the model description provided below is non-technical. More information on the model's equations, assumptions, calibration and validation procedures will be made available from the authors.

³ The model was developed in Powersim, a visual programming software computing the quantitative relationships and influences in the model using the Euler forward integration method. [Technical details on the Euler forward integration procedure are available in Zwillinger (1989).]

⁴ The purpose of the model is to reflect in general terms the frequency behavior of prices and production. As a result, we can set the initial stock levels at arbitrary levels. The model can be calibrated to reflect specific consumption and production levels, if desired.

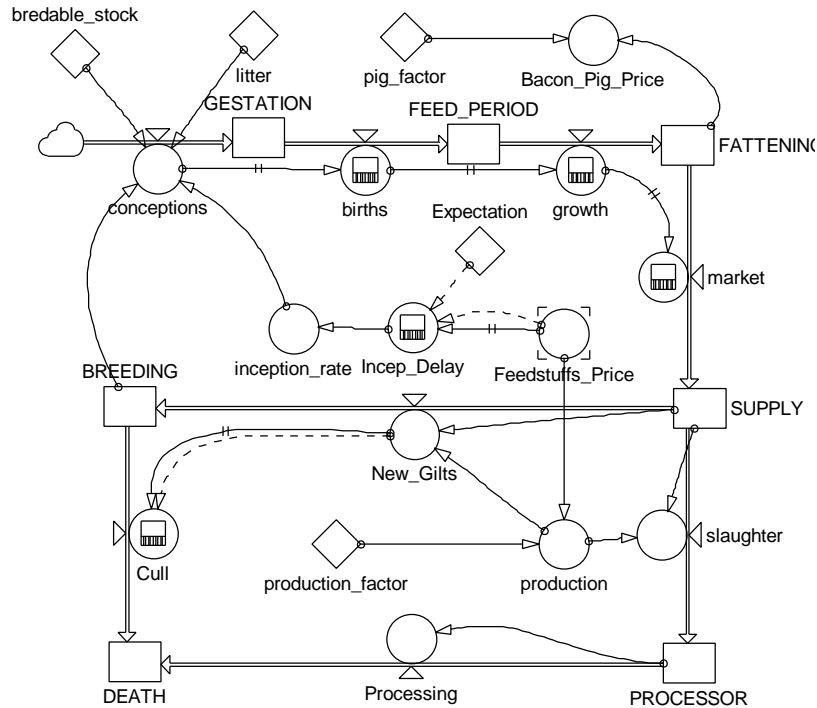


Figure 1. Pig Production structure of the nonlinear and dynamic model of information and coordination

sows is set to twenty-eight months because breeding sows are typically kept for a total of thirty-six months and not used for breeding before the age of eight months. Over their productive life, sows typically have four litters. Given a gestation period of four months, twelve months thus remain for inception and as a consequence, two-sevenths of breedable sows can become pregnant at any point in time.

The inception rate captures the economic impact of fluctuating feedstuffs prices. The inception rate is based on the assumption that, in every period, half the breeder-pigs are breedable sows, a fraction of the (two-sevenths) breeding population that is reproducing at any point in time. There is an adjustment to the inception rate due to the price of feedstuffs. Thus as feedstuffs prices rise, the short-run response of producers is to breed less sows.

The feedstuffs price variable is created to account for its inverse relationship to bacon-pig price. The feedstuffs price of £6 was taken from the maximum observed price in Coase and Fowler

(1935a:131, Curve B, Figure I). The ‘feed factor’ is divided by the bacon-pig price to reflect that bacon-pig prices have a higher fluctuation range than feedstuffs prices.

The feeding period is the first stage in pig growth. The number of pigs in the feeding stage is modified after a growth period of four months. After the feeding period, store-pigs are moved to the second stage in pig growth, where they are fattened for a three-month period before marketing as porker-pigs for the fattening phase⁵. Depending on feedstuffs prices, the supply at the end of the five months fattening phase is diverted to either the slaughterhouse or to breeding.

Bacon-pig price has a maximum value of £10 (Coase and Fowler, 1935a:131, Figure I). The maximum price for bacon is equal to the discrepancy between 10, the maximum price, and the total number of bacon-pigs in fattening, divided by the pig factor. The ‘pig factor’ is introduced to specify that bacon-pig price-quantity supplied relationship⁶. The minimum price at which bacon-pigs can be marketed is £2. This specification is influenced by the size of the bacon-pig herd at the fattening stage ready for the market. The determination of the bacon-pig price in the model is a short-run relation that is not influenced by long-run structural adjustments. The fluctuation of feedstuffs and bacon-pig prices approximate levels of the ones reported in Coase and Fowler (1935a,b). Note that feedstuffs prices and per capita consumption are unknown, and thus profit, may not mirror the amplitude observed in the industry, but the frequency of all results should be correct.

The Static Price Expectation Hypothesis

To examine the static expectation hypothesis, the model uses the assumption of the cobweb theorem that producers assume feedstuffs costs and bacon-pig prices will remain constant during the

⁵ The fattening period is specified separately from the feed period so that the model can be expanded to include variations in the age at which pigs can be slaughtered, diverted to the porker-pig market, or the bacon-pig market by specification of decision rule to characterize arbitrage. (This comment complements footnote 1.)

⁶ The maximum price in the system is set at £10 and the minimum price is £2. The bacon-pig price is defined by a relative price-quantity supplied relationship dependent on an inverse relationship with the bacon-pig inventory in fattening. The price and supply relationship is given as part of a conditional statement that characterizes the direction of the bacon-pig price movement. The equation is, bacon-pig price = 10 - Fattening/pig factor, or bacon-pig price = 2. The bacon-pig price decreases (increases) as pig inventory in the fattening stage increases (decreases), as a ratio of the pig factor.

production period. This is specified by setting to zero the delay of expectations, that is, it specifies that there are no reaction time delays on the part of producers and decision are implemented instantaneously following a price change (see Figure 1). Figure 2 shows the economic components of the model specified to conduct an analysis using assumptions of the cobweb theorem.

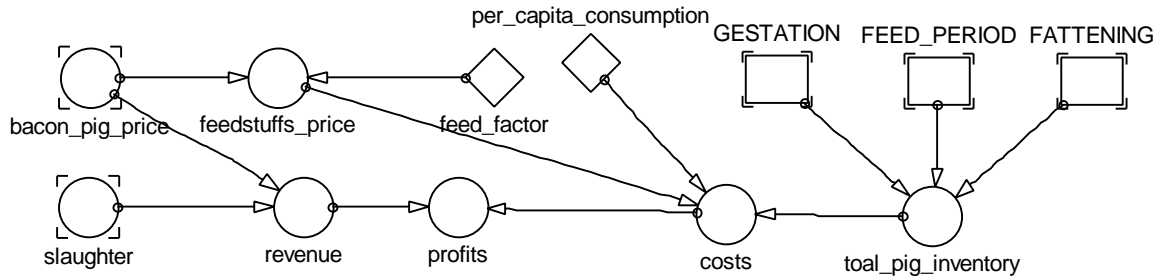


Figure 2. Economic specification of the static price expectation hypothesis

Simulation results in Graphs A and B of Figure 3 depict the bacon-pig price and its relation to the fattening state variable. The bacon-pig price and fattening herd frequencies mirror the two-year (22 months) oscillation patterns that Coase and Fowler (1935a) predicted would happen using the structural assumptions of the cobweb theorem. The price-quantity relationships anticipated by economic theory are accurately depicted as movements in the bacon-pig price are inversely related to ones of the fattening herd. These results support Coase and Fowler's 'critique' that approximated

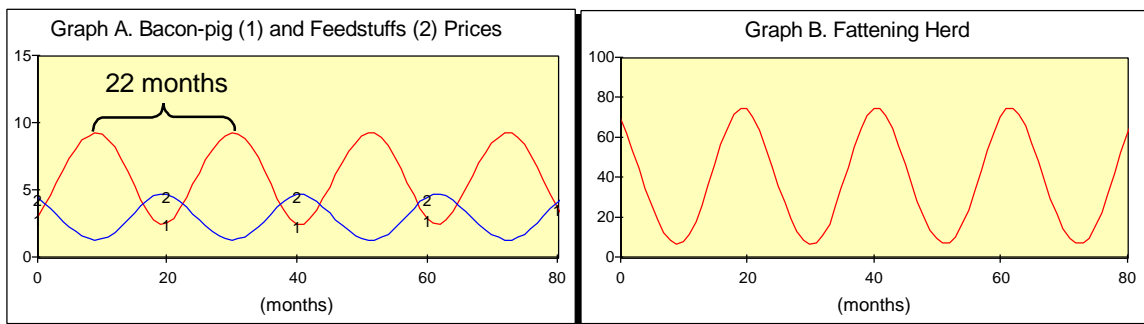


Figure 3. Simulation results of the static price expectation hypothesis

a two-year pig-cycle if farmers held static expectations about prices, and also, if adjustment in breeding herd is carried out immediately following changes in the prices of pigs and of feedstuffs. The model findings thus agree with the outcome of the static price expectation hypothesis that the

cobweb theorem was not relevant to model the pig-cycle in Great Britain during the 1920s and 1930s.

The Time-based Price Expectation Hypothesis

To study the time-based price expectation hypothesis, the model is modified to account for the structure described by Coase and Fowler (1935a) that would replicate industry behavior. The static price expectation hypothesis components in Figure 2 are replaced by the structure shown in Figure 4.

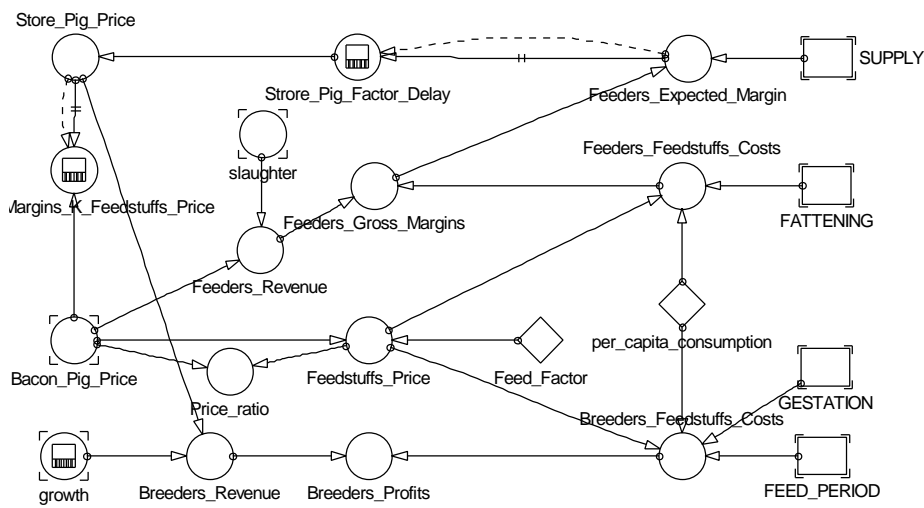


Figure 4. Economic relationships of the time-based price expectation hypothesis

This structure is compatible with description of the industry as provided in the papers. Production stages are disaggregated to distinctively compute store-pig and bacon-pig prices and expected margins assuming the documented time delays. The expectation variable (see Figure 1) was set to twelve months. Indeed, the 'explanation' uncovered that producers held time-based expectations for a period of approximately two years. In the model, the subsequent twelve months time-delays are included through the gestation, feeding, and fattening phases. Expected breeder and feeder margins, the producers' reaction time parameters shown in Figure 4 were set to six months.

Results reproduced by the model yield a bacon-pig price cycle frequency of 41 months as was observed on average in the market (see Graph A, Figure 5). An inverse pattern with the same

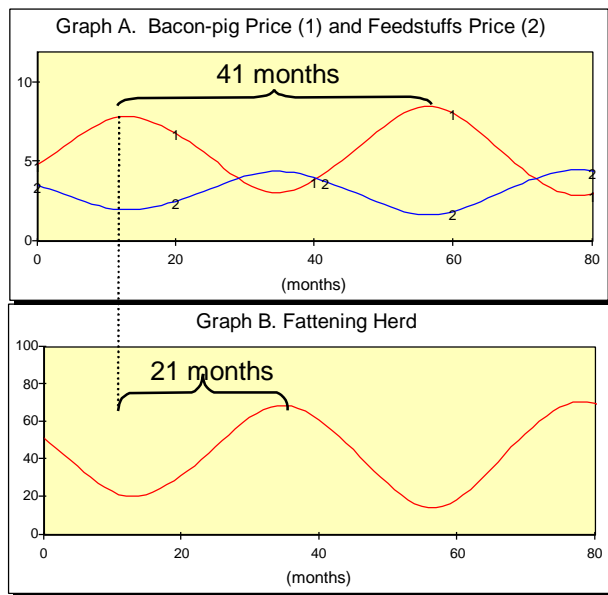


Figure 5. Simulation results of the time-based hypothesis. Prices and herd

breeder and feeder profit margins, and of the feedstuffs/bacon-pig price ratio. For the purpose of their analysis the feedstuffs/bacon-pig price ratio is used as an indicator of fattening relative

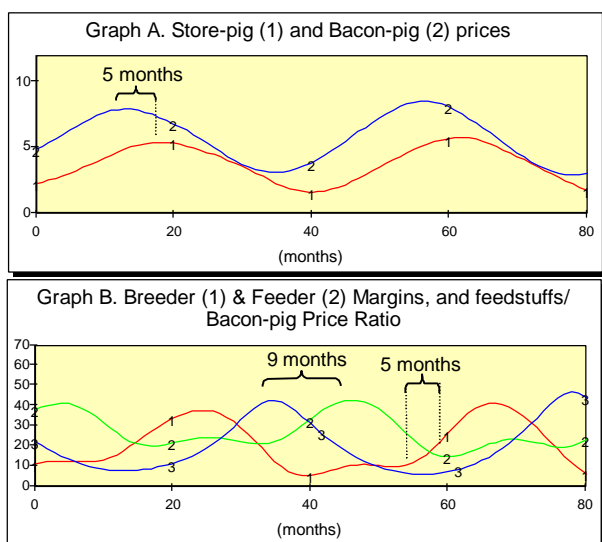


Figure 6. Simulation results of the time-based hypothesis. Prices and margins

breeders and feeders. Therefore this observation supports the notion that breeders do not react immediately to changes in feedstuffs prices but rather to changes in bacon-pig prices because of the nature of the market for store-pigs, which are sold for fattening. Indeed the fatteners do react almost immediately to a change in the feedstuffs/bacon-pig price ratio (see Graph B, Figure 6). Although,

frequency is shown for fattening herd (see Graph B, Figure 5.) Coase and Fowler (1935a) observed industry behavior and noted that there was a 21 months time delay between a change in the direction in price and a change in the direction of the pig inventory, as shown in Figure 5.

Consistent with Coase and Fowler's observation, Graph A in Figure 6 exhibits a time lag of five months between the store-pig and bacon-pig prices. Graph B provides an estimate of

profitability. Coase and Fowler (1935a) detailed that the profit margin for breeders precedes the profit margin for feeders by nine months. Subtracting the total production time of twelve months from the twenty-one months delay between a direction change in price and the direction change in fattening herd gives nine months, which Coase and Fowler stressed is the time delay between the relative profitability of

not mentioned by Coase and Fowler, both profit margins exhibit a cyclical asymmetry. Margins take much longer to increase during expansion phases than they take to decrease during contraction phases. This is because more time is necessary to build the herd (gestation and fattening time delays) than needed to liquidate it (fattening time delay). The argument made Coase and Fowler is valid for herd expansion phases only.

The results obtained with the specification of the model based on Coase and Fowler’s ‘explanation’ clearly satisfy the set of results of the time-based price expectation hypothesis. The model also provides some details about the asymmetric nature of profit margins during pig herd expansion and contraction phases.

The Role of Information and Coordination

After establishing these results Coase and Fowler (1935a) posited that the temporal uncertainty of the bacon-pig price movement was responsible for the asynchronous response by

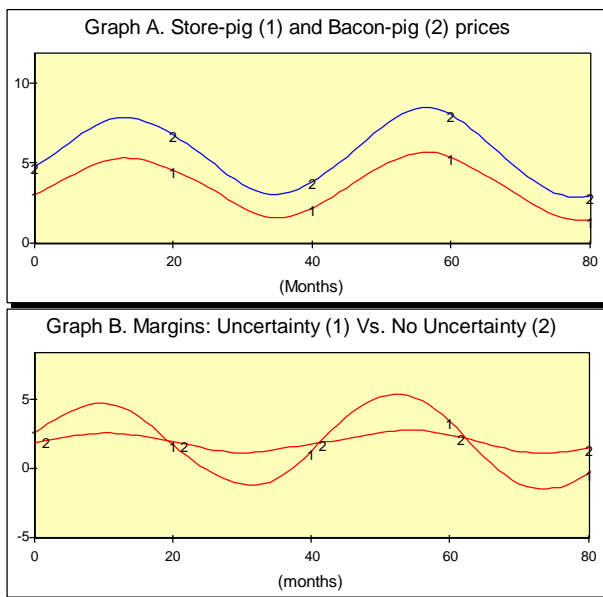


Figure 7. Information and coordination. Contemporaneous prices and margins

breeders, which is a source of temporal uncertainty that creates price and production oscillations in the market. Indeed, if fatteners could predict with accuracy the industry production response (both temporal and volume), bacon-pig and store-pig prices could be aligned and the profit margin for breeders would be contemporaneous to the one of the fatteners. To examine this possibility, the breeders and the fatteners’ expectation margins

were set to zero, assuming no uncertainty so that no time is necessary to respond to a bacon-pig change in profit expectation, hence eliminating price uncertainty (see Figure 3). Assuming constant prices for feeding, their argument is replicated by the model as seen in Figure 7, Graph A. Graph B provides a comparison of the profit margins with

uncertainty (curve 1) and without uncertainty (Curve2). Clearly, the profit margin (even with changing feedstuffs price) would be much more stable if producers could coordinate the price incentive mechanism in time. However interesting are the results of Figure 7, the model did not seem to dampen production cycles in any significant manner. Although a counterintuitive outcome, this result is discussed below by considering the relationship between the structure of the model and its current versus anticipated behavior, in relation to the specification of certain parameters.

Conclusions and Implications

Here, we have reported on a model building effort to better understand commodity cycles using a nonlinear and dynamic model. The model was developed using the pig production structural description and knowledge of research conducted by Coase and Fowler during the 1935-1940 period, because of its thorough macro and microeconomic linkages and availability of information relevant for modeling. Coase and Fowler's approach is intriguing because it seeks to understand the mechanisms of short-run disequilibrium behavior in commodity cycles (that is, how structure (frequency)) influences behavior (amplitude).

Two working hypotheses were tested. As anticipated by Coase and Fowler (1935a) the investigation of the static price hypothesis found that the assumption of the cobweb theorem had a frequency of approximately half the observed cycle. Similarly, the results of the time-based expectation hypothesis replicated all the frequency results observed at the time. That was accomplished by introducing a time expectation delay that oriented the direction of price expectations for a period of twenty-four months, and breeders and feeders expectations of profit margins that specifically reflected the length of the production process. Results showed a cycle with a frequency of forty-one months, a time delay between a change in the store-pig price and the fattening inventory of twenty-one months, and a nine months delay between a change in the feedstuffs/bacon-pig price ratio. All these results are consistent with the ones reported by Coase and Fowler across their series of papers. In addition, the model computed profit margins for breeders

and fatteners and an asymmetry in the profit margins between pig herd expansion and liquidation phases was uncovered.

With regards to what we have learned from producers of today, the findings about the role of information in coordination suggest that better information (shortening the adjustments) does shorten the length of the cycle (by contrasting the effects of the cobweb model with the CF's formulation.) Also, reducing the uncertainty, that is, making the bacon-pig and store-pig prices contemporaneous, makes the profit margins more stable. However, reducing the temporal uncertainty did not have an effect on the volume of production within the model. This counterintuitive finding may be reflective of a few structural issues that must be addressed in future model development.

Note that the two hypotheses examined issues related to the frequency of the cycle. The dampening of the amplitude is more closely related to the static specification within the model of parameters that would likely provide feedback adjustment in terms of amplitude behavior in time. For instance, the 'explanation' includes detailed information on how variations in profit margins influence investment behavior in breeding herd adjustments. By contrast, the current model specification is strictly price-based. Similarly, the demand relationship specified in the model is a fixed quantity per capita. As such consumers do not adjust the quantity demanded as the price vary. Further work with a specific an inelastic inverse price-quantity relationship at the demand interface might show that the structure of hog production is also affected once this information feedback is specified. The temporal uncertainty and time reaction delays, determine more the frequency of cycles, while specific information about supply and demand, is more closely related to cycle (amplitude) issues. Clearly, information about reaction delays and quantities have economically important value and are worthy of further inquiries because they are interrelated in time.

Literature Cited

- Chavas, J.-P., and Holt, M.T. (1991). On Nonlinear Dynamics: The Case of the Pork Cycle. *American Journal of Agricultural Economics*, 73, 819-828.
- Cloutier, L.M., Sonka, S.T. (1998). "A System Dynamics Model of Information Feedback and Activity Coordination in an Agricultural Value Chain." International System Dynamics Conference, Quebec City, QC, Canada, July 20-23 1998.
- Coase, R.H. (1940). The Analysis of Producers' Expectations. *Economica*, 7, 280-292.
- Coase, R.H. (1937). The Nature of the Firm. *Economica*, 4, 386-405.
- Coase, R.H. (1960). The Problem of Social Cost. *Journal of Law and Economics*, 3, 1-44.
- Coase, R.H., and Fowler, R.F. (1935a). Bacon Production and the Pig-cycle in Great Britain. *Economica*, 2, 142-167.
- Coase, R.H., and Fowler, R.F. (1935b). The Pig-Cycle: A Rejoinder. *Economica*, 2, 423-428.
- Coase, R.H., and Fowler, R.F. (1937). The Pig-cycle in Great Britain: An Explanation. *Economica*, 4, 55-82.
- Cohen, R. (1934). Agricultural Reorganisation and Price Control. *Economic Journal*, 44, 434-452.
- Cohen, R., and Barker, J.D. (1935). The Pig-Cycle: A Reply. *Economica*, 2, 408-421.
- Doanes Agricultural Report (1998). Volume 61, 17-1, 4/24.
- Ezekiel, M. (1927a). Statistical Analyses and "Laws" of Price. *Quarterly Journal of Economics*, 42, 199-227.
- Ezekiel, M. (1927b). A Statistical Examination of Factors Related to Lamb Prices. *Journal of Political Economy*, 35, 233-260.
- Ezekiel, M. (1938). The Cobweb Theorem. *Quarterly Journal of Economics*, 52, 255-280.
- Hayes, D.J., and Schmitz, A. (1987). Hog Cycles and Countercyclical Production Response. *American Journal of Agricultural Economics*, 69, 762-770.
- Kaylen, M.S. (1988). Vector Autoregression Forecasting Models: Recent Developments Applied to the U.S. Hog Market. *American Journal of Agricultural Economics*, 70, 701-712.
- Ministry of Agriculture and Fisheries. (1932). Report of the Reorganisation Commission for Pigs and Pig Products. Published by His Majesty's Stationary Office: London.
- Morecroft, J.W.D., and Sterman, J.D. (eds.). (1994). *Modeling for Learning Organizations*. Portland, OR: Productivity Press.

- Murray, K.A.H. (1933). The Future Development of the Pig Industry in Great Britain. *Empire Journal of Experimental Agriculture*, 1, Bulletin No. 3.
- Nerlove, M. (1958). Adaptive Expectations and Cobweb Phenomena. *Quarterly Journal of Economics*, 72, 227-240.
- Porter, B. 1969. *Synthesis of Dynamical Systems*, Nelson: London.
- Rosen, S., Murphy, K.M., and Scheinkman, J.A. (1989). Hog and Cattle Cycles and the Period of Production. Manuscript. University of Chicago: Chicago, IL.
- Rowley, R., and Cloutier, L.M. (1997). Simulated Dynamics: From Mimicry and Cybernetics to Quantitative Economics and System Dynamics. Paper presented at the meeting of the History of Economics Society, Charleston, SC, June 20-23.
- Ruth, M. and Hannon, B. (1997). *Modeling Dynamic Economic Systems*, Springer-Verlag: New York.
- Streips, M.A. (1995). The Problem of the Persistent Hog Price Cycle: A Chaotic Solution. *American Journal of Agricultural Economics*, 77, 1397-1403.
- Zwillinger, D. (1989). *Handbook of Differential Equations*, Academic Press: New York.