Staff Paper P04-12 September 2004

Staff Paper Series

Estimating Investment Rigidity within a Threshold Regression Framework: The Case of U.S. Hog Production Sector

by

Brenda L. Boetel, Ruben Hoffmann, and Donald J. Liu

DEPARTMENT OF APPLIED ECONOMICS
COLLEGE OF AGRICULTURAL, FOOD, AND ENVIRONMENTAL SCIENCES
UNIVERSITY OF MINNESOTA

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Brenda L. Boetel, Ruben Hoffmann, and Donald J. Liu*

* Brenda L. Boetel if an Assistant Professor in the Department of Agricultural Economics at the University of Wisconsin-River Falls; Ruben Hoffmann is a Ph.D. student in the Department of Economics at the Swedish University of Agricultural Sciences; Donald J. Liu is an Associate Professor in the Department of Applied Economics at the University of Minnesota. Senior authorship is not assigned.

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The importance of the U.S. swine industry is far-reaching and can be highlighted by its economic contributions to different sectors along the supply chain involving hog producers, pork processors, and consumers. According to the National Pork Producers Council (NPPC), the industry supported an estimated 800,000 domestic jobs in 2002 and generated more than $72 billion in total domestic economic activities. Furthermore, the U.S. is a leading pork exporter, tied with Denmark and second only to Canada, with its exports valued at $1.5 billion in 2002.

Of the $72 billion worth of domestic economic activities, receipts from hog sales account for more than $11 billion per year. The hog sector also contributes an additional $27 billion from the utilization of corn, soybean, and other inputs. The structure of the hog production sector has changed dramatically during the past decade, with large hog operations becoming increasingly dominant. It is estimated that 80 percent of the hogs slaughtered today is supplied by farmers producing 5,000 heads or more per year (NPPC). Many factors have contributed to this structural change in hog production, including the advent of new production technology, the increased access to international markets and subsequent expansion of exports, and improved access to financial capital through various institutional innovations such as contracting and other forms of vertical arrangements.

As the U.S. hog production sector has changed to include larger operations, greater amounts and more specialized types of capital are required to enter the production arena. For example, it takes more specialized types of machinery to run the complex operations, and larger and more custom-designed facilities to house the greater number of hogs, along with greater investment in manure management for those facilities. The above type of inputs is typically referred to as quasi-fixed inputs because, while changes in the capital stock are feasible, there are costs associated with the adjustment. The classical theory of investment typically assumes a convex adjustment cost function, dictating that there is a smoothing over time in the adjustment of quasi-fixed input from the current stock level to the desirable state (e.g., Lucas). The optimization principle also dictates that investment or disinvestment will occur, facing market price changes, to maintain the equality between shadow value of capital and marginal adjustment costs. However, when there exist irregularities in the adjustment cost function, investment rigidities may be present such that producers maintain the same level of quasi-fixed inputs and, hence, produce more or less the same amount of output even though the economic situation has changed perceptibly.

That farmers do not adjust their quasi-fixed input as the market price changes is a long-standing issue in agricultural economic literature (e.g., Johnson; Edwards; Johnson and Quance; Chambers and Vasavada; Vasavada and Chambers; Nelson, Braden and Roh; Howard and Shumway). This problem is typically referred to as asset fixity, investment rigidity/irreversibility and investment hysteresis. There are many reasons underlying the phenomenon. For example, as put forth by Johnson, rigidities in capital investment can occur when the shadow value of a capital asset falls between an upper and a lower threshold as defined, respectively, by the asset's acquisition price and its salvage value.[1] That is, the asset price asymmetry between investment and disinvestment can result in a range of inaction in which it is neither worthwhile investing another unit nor profitable liquidating the existing ones. Hsu and Chang show that the inaction range can also be caused (and hence made more pronounced) by non-differentiability, at the point of zero investment, in the conventional adjustment cost function associated with quasi-fixed input investment/disinvestment. Unifying the literature, Abel and Eberly propose an "augmented adjustment cost function" which includes (i) purchase/resale prices of the asset (allowing for Johnson's price asymmetry at the origin), (ii) the conventional adjustment costs function (allowing for Hsu and Chang's non-differentiability at the origin), and (iii) a fixed adjustment cost component (however small the investment/disinvestment is). In their augmented adjustment cost framework, capital investment is a non-decreasing function of the asset's shadow price but is not responsive to price changes as long as the shadow value is within a range of inaction defined by an upper and a lower threshold. The authors show that the range of

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[1] Several reasons have been proposed to explain this asset price asymmetry. Arrow suggests that the discrepancy between acquisition and salvage prices may be due to the existence of installation costs, disposal costs, and other related transactions costs that must be added either only to the purchase price or only to the resale price. Dixit and Pindyck point out that the price gap may also be due to an Akerloff-type lemon effect (Akerloff) when buyers are uncertain about the quality of used machines. Oude Lansink and Stefanou argue that the price disparity may arise from government regulations requiring firms to pay back an investment subsidy if the asset is liquidated prematurely as dictated by the subsidy program.

investment rigidity is further enlarged by the inclusion of the fixed cost component in the adjustment cost function.

Given the possibility of the existence of an inaction range in capital adjustment, it is important that this aspect of decision making is incorporated when modeling hog producers' quasi-fixed input demand and output supplies. Without explicit consideration of the inaction regime, any estimate of the model may be biased and, hence, the accompanying policy conclusions erroneous. The issue of investment rigidity may be more than merely a modeling concern for several reasons. Pietola and Myers argue that investment rigidities may create entry barriers by granting cost advantages to the incumbents, reducing the competitiveness of the industry. Further, one can envision the problem associated with a situation in which investment rigidities are coupled with other frictions along the supply chain of the industry. For example, if the retail output price cannot adjust quickly enough to a level warranted by the existing supply and demand conditions, the gravity of investment rigidity at the farm level may be further aggravated by the retail price inertia which holds the shadow value of farm assets within the upper and lower thresholds defining the inaction regime.[2] As a result, profit maximizing hog producers may find themselves trapped in a prolonged state of either excess supply or excess demand, to the detriment of the economic vitality of the swine industry and its affiliated rural communities. In these circumstances it may be desirable to devise policies to alleviate the problems caused by asset fixity and, in this regard, it is essential to first ascertain whether the rigidity exists and, if so, to what

[2] The output price inertia may be due to frictions in the pricing institution, lags in shipment and information, etc.

extent it has impeded the industry from achieving a smooth and timely adjustment to the long-run equilibrium level of quasi-fixed input stock.

The purpose of this study is to estimate the U.S. hog supply with explicit allowances for the implications of asset fixity in the employment of quasi-fixed inputs. Specifically, two questions are addressed. First, does an inaction or sluggish regime exist in the demand for quasi-fixed input in the U.S. hog production sector? Second, what is the magnitude of this rigidity and to what extent has it impeded adjustment in capital stock and, hence, output quantity toward their long-term equilibrium levels? It is only after answers to these questions are found can one begin to address the issue of whether there is a need for policy intervention and, if so, how such policy should be formulated.

The organization of the paper is as follows. In Section 2, Abel and Eberly's unified framework of investment under uncertainty with sunk costs is discussed for a representative hog producer. A three-regime threshold quasi-fixed input decision rule allowing for investment, disinvestment and inaction is derived. In Section 3, a brief exposition of the threshold estimation and testing procedures recently advanced by Hansen (1996, 1999, 2000) is presented. While there are at least two empirical studies dealing with the estimation of threshold investment in agriculture (Oude Lansink and Stefanou; Pietola and Myers), both employ a Tobit type estimation procedure for censoring data and, hence, exclude one of the three capital adjustment regimes.[3] In Section 4, estimation results pertaining to the demand for quasi-fixed inputs are

[3] Oude Lansink and Stefanou entertain only the investment and disinvestment regimes, whereas Pietola and Myers estimate only the investment and inaction regimes.

reported. The three-regime model is found to perform well based on Hansen's likelihood ratio tests and the conventional forecasting evaluation criteria (e.g., the R-squares, and in-sample and out-of-sample Theil U statistics). In Section 5, a hog output supply equation, specified in part as a function of lagged quasi-fixed input stock, is estimated. The estimated hog supply equation and the demand equation for quasi-fixed input are then used in Section 6 to derive the short-run and long-run elasticities of quasi-fixed input stock and hog output supply (with respect to key exogenous variables such as hog-feed price ratio and hog price risk). The two estimated equations are also used to simulate the effect on quasi-fixed input stock and output supply of a change in the range of inaction, thus providing insights into the extent to which investment rigidities have impeded adjustments in those variables. Section 7 concludes.

Conceptual Framework

Consider a production process in which a breeding-farrowing-finishing hog producer uses a vector of quasi-fixed inputs and a vector of costlessly adjustable variable inputs to produce a single output. Examples of quasi-fixed inputs for a hog farm operation are breeding herd, feedlot facilities and farm machinery, while corn and soybean meal are examples of costlessly adjustable variable inputs. Subject to adjustment costs, the stock of quasi-fixed inputs can be altered at any point in time t via investment/disinvestment. This stock of quasi-fixed inputs is assumed to evolve according to

(1) $dK_t = (I_t - \delta K_t)\, dt,$

where K_t is the vector of capital stocks at time t, I_t is the vector of gross investments at time t, and δ is the rate of depreciation.

Given the capital stock K_t, the hog producer at each point in time chooses the amount of gross investment in quasi-fixed input and the amount of variable inputs, denoted by V_t, to maximize the expected present value of the profit stream. The value of the firm can be written as:

(2) $J(\rho_t, \varpi_t, \kappa_t, K_t, \Sigma_\theta)$

$$= \max_{\{I_{t+s}, V_{t+s}\}} \int_0^\infty E_{\theta_t} \left[\rho_{t+s} Q(K_{t+s}, V_{t+s}) - \varpi_{t+s}' V_{t+s} - \kappa_{t+s}' I_{t+s} - C(I_{t+s} | K_{t+s})\right] e^{-rs} \, ds,$$

where apostrophe denotes the transpose operator; ρ the price of hog output; ϖ the variable input price vector; κ the quasi-fixed input price vector; Q(K, V) the hog output quantity as a function of capital stock and variable input quantity; θ_t a random variable used to represent randomness in technology, the price of variable input, or the demand facing firms;[4] E the expectation operator, taken with respect to the distribution of θ_t (with its parameters represented by Σ_θ); e the exponential operator; r the discount rate; and C(.) the adjustment cost function associated with the gross investment. The properties of C(.) as well as their implications on the structure of quasi-fixed input investment will be discussed shortly. Note that the hog producer is assumed to be risk neutral and the maximization problem in (2) is subject to the evolution of the capital stock in (1) and the evolution of the underlying random variable θ_t. Specifically, it is

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[4] Given the pervasiveness of output price uncertainty in the hog enterprise, θ is used to capture the randomness in hog output prices in the empirical section of the study.

conventional and convenient to assume that θ_t follows a geometric Brownian motion with drift (e.g., Abel and Eberly; Dixit and Pindyck):

(3) $$d\theta_t = \alpha\, \theta_t\, dt + \sigma\, \theta_t\, dz_t,$$

where z_t is a standard Wiener process. Making use of (1) and (3) and invoking Ito's lemma, the Hamilton-Jacobi-Bellman equation (time subscript t suppressed) can be written as:

(4) $$r\, J(\rho, \varpi, \kappa, K, \Sigma_\theta) = \max_{\{I,\, V\}} \{\rho\, Q(K, V) - \varpi'\, V - \kappa'\, I - C(I\, |K) + (I - \delta\, K)\, J_K + J_t\},$$

where the subscript now denotes the derivative, with J_K being the shadow value of quasi-fixed inputs, and $J_t \equiv \alpha\, \theta\, J_\theta + \frac{1}{2}\, \sigma\, \theta^2\, J_{\theta\theta}$ reflecting the effect of θ_t on the value of the farm. Note that Σ_θ now contains only the first two moments of θ (due to the two terms in J_t). Note also that the last two terms in (4), $(1 - \delta\, K)\, J_K + J_t$, can be interpreted as the "capital gain" of the farm [i.e., E[dJ]/dt] and the equation dictates that, at equilibrium, the required return of the farm (rJ) must equal the maximized expected profit flow plus the expected capital gain (Abel and Eberly; Dixit and Pindyck).

The firm's investment demand in quasi-fixed input can be derived by differentiating equation (4) with respect to the quasi-fixed input price, κ, and applying the envelope theorem:

(5) $$I = (1 - J_{K\kappa})^{-1}\, (-\, r\, J_\kappa - \delta\, K\, J_{K\kappa} + J_{t\kappa}).$$

Equation (5) [and the associated Hamilton-Jacobi-Bellman Equation in (4)] suggests that the underlying determinants of the investment demand include output price (ρ), variable input prices (ϖ), quasi-fixed input prices (κ), capital stocks (K), discount rate (r), and the first two moments of the underlying random variable (Σ_θ).[5] However, in its current form, this equation does not explicitly account for the implication of the structure of the adjustment cost function associated with quasi-fixed input investment. Following Abel and Eberly, it is assumed that the producer considers in his or her capital investment decision a so-called "augmented adjustment cost function" which includes the purchase/resale price of the capital [as reflected by the term $\kappa_{t+s}' I_{t+s}$ in (2) and (4)] and the fixed and variable adjustment costs [as captured by the term C(.) in (2) and (4)]. Each of the three cost components is briefly discussed below.

To allow for a disparity between purchase and resale prices of quasi-fixed input, κ is generalized as: $\kappa_t = \kappa_t^+$ if $I_t > 0$ and $\kappa_t = \kappa_t^-$ if $I_t < 0$. Note that in the special case where $\kappa_t^+ = \kappa_t^-$, the full purchase cost can be recovered upon resale and, hence, the investment is fully reversible. On the other hand, if $\kappa_t^+ > \kappa_t^- > 0$ the recovery is only partial and some irreversibility in quasi-fixed input investment exists.

The fixed adjustment costs are nonnegative costs incurred whenever positive or negative gross investment occurs, however small. For example, managerial decision costs, fixed costs of placing orders, or firm reorganization costs are all fixed adjustment costs. Because investment and disinvestment are different courses of action, the fixed adjustment costs required to partake in one verse the other may not be the same. Denoting this fixed cost by ϕ and allowing for asymmetry, this component of the adjustment costs can be written as: $\phi = \phi^+$ if $I_t > 0$ and $\phi = \phi^-$ if $I_t < 0$.

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[5] Assigning a specific functional form to the value function J, (5) would also give the corresponding functional form for the quasi-fixed input investment demand equation.

Finally, the third cost component is the variable adjustment costs corresponding to the conventional adjustment cost function, which is typically assumed to be strictly convex, nonnegative and at a minimum of zero for I = 0. However, Abel and Eberly allow this component to contain a kink at I = 0 to account for investment/disinvestment asymmetry in variable adjustment costs. Denote this variable adjustment cost component by $\Psi(I\,|K)$ and express its right-hand and left-hand derivatives at I = 0 by Ψ_I^+ and Ψ_I^-, respectively.[6]

Given the structure of the three cost components, Abel and Eberly show that the optimal demand for investment in quasi-fixed input obeys the following threshold rule:

$$(6) \qquad I \quad \begin{matrix} > 0 \\ = 0 \\ < 0 \end{matrix} \quad \text{if} \quad \begin{matrix} \lambda_U < \lambda & \\ \lambda_L \leq \lambda \leq \lambda_U, \\ \lambda < \lambda_L & \end{matrix}$$

where $\lambda \equiv J_K$ is the shadow value of the quasi-fixed input, and λ_U and λ_L are the upper and lower thresholds separating producer's behavior into investment, inaction and disinvestment regimes. Abel and Eberly show that the magnitude of the threshold depends on the purchase/resale price, the fixed adjustment cost, and the marginal variable adjustment cost at the origin. Specifically, $\lambda_U = \kappa^+ + \phi^+ + \Psi_I^+$ and $\lambda_L = \kappa^- + \phi^- + \Psi_I^-$.

Note that the threshold variable, λ, separates the sample into different regimes by comparing it against the thresholds, λ_U and λ_L. To deal with the problem that the

[6] Given the notations, the cost function C(.) in (2) and (4) is simply $\Psi(.) + \phi^+$ (when I > 0) or $\Psi(.) + \phi^-$ (when I < 0) and Abel and Eberly's augmented adjustment cost function is $C(.) + \kappa^+ I$ (when I > 0) and $C(.) + \kappa^- I$ (when I < 0).

shadow value of an asset is unobservable, one notes that λ is, in part, a function of the output price, and hence there exists a mapping between λ and ρ (Chavas, p.121). Denoting the corresponding upper and lower thresholds in the output space by ρ_U and ρ_L, respectively,

$$(7) \qquad I \quad \begin{matrix} > 0 \\ = 0 \\ < 0 \end{matrix} \quad \text{if} \quad \begin{matrix} \rho_U < \rho \\ \rho_L \leq \rho \leq \rho_U. \\ \rho < \rho_L \end{matrix}$$

Instead of casting the original investment demand equation in (6) from λ space onto output space [as in (7)], a version of the threshold model with a variable input price as the threshold variable could have been adopted. As the shadow value of quasi-fixed input is a function of both output and input prices, it would be beneficial to include both prices as threshold variables for sample separation. However, this extension would render the model too complicated econometrically.[7] To stay within the framework of a single threshold variable while addressing the issue that both output and input prices matter in sample separation, an output-input price ratio will be utilized as the threshold variable in the empirical section.

The next step is to incorporate the threshold rule in (7) into the optimal demand for investment in quasi-fixed input in (5). Following Oude Lansink and Stefanou, equation (5) is simplified as $I = \pi' Z$ where Z is a vector of quasi-fixed input investment demand determinants (or their transformations) and π is a vector of parameters.

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[7] Note that a threshold model with multiple threshold variables is different from a threshold model with multiple thresholds. The model in (7) allows for multiple thresholds (ρ_U and ρ_L) but only one threshold variable (ρ). The procedure for estimating a threshold model with multiple threshold variables is not available.

Incorporating the threshold rule in (7) into $I_t = \pi' Z_t$, the quasi-fixed input investment demand can be concisely written as:

(8) $$I = \pi^{+\prime} Z * G(\rho > \rho_U) + 0 * G(\rho_L \le \rho \le \rho_U) + \pi^{-\prime} Z * G(\rho < \rho_L) + \mu,$$

where G(.) is an indicator function taking a value of one if the condition inside the parentheses is true and zero otherwise, $\pi^{+\prime}Z$ and $\pi^{-\prime}Z$ specify the optimal investment when $\rho > \rho_U$ and $\rho < \rho_L$, respectively, and μ is the econometric error term included for estimation purposes.

In applications involving aggregate data it is likely that observations with zero investment are rare or non-existent (even when the price falls between ρ_U and ρ_L). However, the model still suggests a relatively unresponsive adjustment in the stock of quasi-fixed input when the price falls between the upper and lower thresholds. To anticipate the smoothing out of zero investment in the aggregate data, the inaction regime in the threshold rule is replaced by a so-called "sluggish regime." Accordingly, equation (8) is modified such that

(9) $$I = \pi^{+\prime} Z * G(\rho > \rho_U) + \pi^{O\prime} Z * G(\rho_L \le \rho \le \rho_U) + \pi^{-\prime} Z * G(\rho < \rho_L) + \mu,$$

where $\pi^{0\prime} Z$ is the optimal investment in the sluggish regime. Note that if π^{O} is not found to be statistically different from zero, the sluggish regime reduces to the inaction regime.

<u>Threshold Estimation Procedures</u>

The econometric procedures for estimating the threshold investment demand equation in (9) are based on the work of Hansen (1996, 1999, 2000) who initially develops the estimation procedure and asymptotic theory for the case of single threshold (i.e., two regimes), and later extends the analysis via a three-stage procedure to accommodate for double-threshold (i.e., three-regime) models such as the one entertained in the current study.[8] In this section, the procedure for single-threshold models is discussed first, followed by an outline on the three-stage extension and, concluded by Hansen's procedure on choosing among models with different numbers of thresholds.

With only one threshold, the three-regime model in (9) reduces to

$$(10) \quad I = \pi^{+\prime} Z * G(\rho > \rho_U) + \pi^{-\prime} Z * G(\rho \leq \rho_U) + \mu,$$

where ρ_U is used in (10) to represent the single threshold and π^+ and π^- denote the associated slope parameters for the two regimes. The relevant statistical tasks here include: (i) estimating the slope parameters (π^+ and π^-) and the threshold parameter (ρ_U), and (ii) testing for the statistical significance of the slope coefficients and constructing the confidence interval for the threshold estimate. Conditional on the estimate of ρ_U, (10) is linear in π^+ and π^- and hence the slope coefficients can be obtained by ordinary least squares. An estimate of ρ_U can be found via a grid search among possible values of ρ_U such that the sum of squared errors function is minimized. To limit the search, one could use the observed values of ρ in the sample, with possible

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[8] The 1996 article shows how to test for the existence of a threshold effect using a bootstrap technique; the 1999 article discusses procedures for threshold regression with panel data and the three-stage procedure for dealing with double thresholds; and the 2000 article deals with the computation of the confidence interval for the threshold estimate.

trimming of extreme values, as candidates for the optimal threshold. That the slope coefficients are conditional on the threshold estimate is a dependency which may render inferences on π^+ and π^- complicated. However, Hansen (2000) shows that this dependency is not of first-order asymptotic importance and, therefore, inferences on the slope coefficients can be proceeded as if the threshold estimate were the true value and the usual critical values apply. As to the construction of the confidence interval for the threshold estimate, Hansen (2000) derives the asymptotic distribution of a likelihood ratio test statistic under the null hypothesis that the threshold parameter equals a specific value. With homoskedasticity, the asymptotic critical value for the test can be computed as $C(s) = -2 \ln(1 - (1- s)^{0.5})$, where s is the size of the test.[9] By inversion, Hansen (2000) then shows how one can derive the asymptotic confidence interval for the threshold coefficient.

To apply the above single-threshold procedure to the double-threshold model in (9), Hansen's (1999) three-stage extension is adopted. The first stage focuses on the dominating threshold of ρ_U and ρ_L by assuming that the model contains only one threshold. In stage two, the second threshold is introduced and estimated, holding constant the threshold obtained in the first stage. While the estimate of this second threshold is asymptotically efficient, the first threshold estimate is not because it was obtained without accounting for the second threshold. To render the first threshold asymptotically efficient, Hansen introduces a third stage in which the first threshold is

[9] For example, the 5 percent and 1 percent critical values are 7.35 and 10.59, respectively.

re-estimated while holding constant the other threshold at the stage-two estimation level. Note that since each of the three stages involves the estimation of only one threshold, the previously discussed single-threshold procedure applies.

With both the single- and double-threshold models already estimated in the three-stage procedure, one is in a convenient position of entertaining the question of which model fits better the data. To determine the number of thresholds, consider the following two sequential tests:

Test 1:	Null:	no threshold	[i.e., a one-regime model][10]
	Alternative:	single threshold	[i.e., equation (10)]
Test 2:	Null:	single threshold	[i.e., equation (10)]
	Alternative:	double threshold	[i.e., equation (9)]

If the null hypothesis in Test 1 is not rejected, there is no support for asymmetry and one infers that the demand for investment in quasi-fixed input is a continuous function of market prices. On the other hand, if the null hypothesis in Test 1 is rejected, one proceeds to Test 2. A failure to reject the null hypothesis of single threshold in Test 2 would give credence to the inference that there may indeed be only two investment regimes with asymmetric responses to price changes. On the other hand, a rejection of the null hypothesis in Test 2 would lend support to the alternative hypothesis that the investment demand in quasi-fixed input has three regimes: an investment regime, a sluggish regime and a disinvestment regime.

[10] Under this null hypothesis the investment demand equations in (9) and (10) reduce to the conventional one-regime model of $I = \pi' Z + \mu$, which can be estimated by the least squares method.

The likelihood ratio statistics for Test 1 and Test 2 can be computed in the usual way. However, the standard chi-squared critical values are inappropriate because the threshold parameters (ρ_U in Test 1, and ρ_U and ρ_L in Test 2) have to be selected in some data-dependent fashion (e.g., the grid search). Moreover, the conventional likelihood ratio test is not applicable because the threshold parameter in question is not identified under the null hypothesis that such threshold does not exist (Hansen, 1996). Following Andrews and Ploberger, Hansen (1967) addresses the above issues by focusing on test statistics that do not require *a priori* knowledge about the thresholds. For example, one of Hansen's test statistics is obtained by taking the "supreme" of all the conventional likelihood ratio statistics computed from the candidate pool of the threshold parameter. The likelihood ratio statistic can then be compared against the critical values generated by the bootstrap procedure proposed in Hansen's 1996 seminal article.[11]

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[11] Denote the transformed likelihood ratio statistic (e.g., Supreme LR, Average LR) as G. First, Hansen derives the asymptotic distribution of G, which still depends on the nuisance parameter (ρ's) and thus its critical values still cannot be tabulated. Second, he resorts to a p-value transformation of G. Specifically, let $F(G^0)$ denote the distribution function of G^0, where G^0 is the null distribution of G. Then, $p \equiv 1 - F(G^0)$ has a null distribution of uniform [0,1], thus free of nuisance parameters. The test is to reject the null if $p \leq s$, where s is the size of the test (e.g., 5%). Third, since the null distribution function F is not directly observable, Hansen approximates F using standard bootstrap techniques. The procedure is to simulate G (e.g., Supreme LR, Average LR) J times (say, J = 300) by appending an independently, identically distributed standard normal random variable to the regression score ($Z\ \mu$) appearing in the expression of the likelihood ratio statistic. Then, arrange the J simulated G's in ascending order, and treat this simulated distribution of G as a discrete approximation of F. Finally, for a test size of say 5%, one picks the 95th percent highest element of the simulated G's as the critical value and rejects the null if the test statistic G is greater than that critical value. Hansen shows that the distribution of F can be approximated by the proposed bootstrap procedure to any desired degree of accuracy by making J sufficiently large.

Estimation Results: Breeding Herd Investment Equation

Quarterly data from 1976 through 1999 are employed to estimate the demand for investment in quasi-fixed input, i.e., equation (9). This time period should be sufficiently long to reflect changes in the quasi-fixed input stock at the farm level and should allow for the different regimes of investment/disinvestment to manifest.

Due to the lack of consistent time series data for such variables as facilities and machinery specific to the U.S. hog production sector, the only quasi-fixed input (K) included in the estimation is the breeding stock.[12] The dependent variable is the breeding herd investment, which is computed in accordance with (1) as the change in breeding stock (K_t - K_{t-1}) plus the depreciation from the previous quarter (δ K_{t-1}). The independent variables included in the estimation are the lagged breeding stock, hog output price, an output price risk term, farm wage, feed cost, sow price, interest rate, the number of pigs per litter, the number of hogs on farm, and quarterly dummy variables. The depreciation rate used in computing the dependent variable is specified as 10 percent per quarter, which reflects the number of years for which a sow is typically retained for production purposes.[13] The pig size per litter variable is included to

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[12] Chang and Stefanou include farm labor, cow herd size, real estate, and equipment as quasi-fixed inputs in their Pennsylvania dairy farm study. Oude Lansink and Stefanou include machinery and root-crop acreage as quasi-fixed inputs in their Dutch crop farm study. Both studies utilize panel data which are richer in information. In their dairy study using annual time series data, Howard and Shumway include cow herd size and labor as quasi-fixed inputs. However, quarterly farm labor surveys that generated the annual labor data were discontinued after April 1981 (Howard and Shumway, p.841).

[13] A sow is typically retained for 2.5 to 3 years, implying a straight-line depreciation of 10 to 8 percent per quarter, respectively. Mindful of the potential pitfall that the estimation results may be sensitive to the choice of the depreciation rate, different rates

account for the effect on investment of breeding technology and the inclusion of the number of hogs on farm is to capture the investment effect of farm capacity.

Data on breeding stock are obtained from the *Livestock, Dairy and Poultry Situation and Outlook* (USDA/ERS, 1970-2002). The hog output price (ρ) is the seven market average slaughter price for all grades of barrows and gilts and the data are from the *Red Meats Yearbook* (USDA/ERS, 2002). To capture the effect of output price uncertainty (Σ_θ) on quasi-fixed input investment, the price data are also used to generate a time series of conditional standard deviations of the barrow and gilt price.[14] Farm labor wage and feed cost are used to represent variable input prices (ϖ). For the years 1976 through 1990 the wage data are from the *Farm Employment and Wage Rates 1910 – 1990* (USDA/ERS, 1991); for the years 1991 through 1994 they are from personal communication with David Brinkley, the data keeper at USDA/NASS; and for the year 1995 through 1999 they are from the USDA/NASS website. As to the feed cost, it is computed as a weighted average of the prices of #2 yellow corn and 48 percent soybean meal. The weight used is the same as in Holt and Johnson; six-sevenths for corn price, and one-seventh for soybean meal price, both measured on an equivalent weight basis. The data for #2 yellow corn prices are from the *Red Meats Yearbook*, whereas the data

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were entertained. As expected, the regression coefficients under alternative depreciation rates are identical with the exception of the lagged breeding stock coefficient. Furthermore, the computed adjustment rates (of moving the current herd size toward the long-run equilibrium level) are not sensitive to the variation in the lagged breeding stock coefficients.

[14] A GARCH(1,1) model is estimated from which the condition variances and standard deviations are generated. The adjusted R^2 is 0.67, with a Durbin-Watson statistic of 1.83. A plot of the standardized residuals of the GARCH model suggests that they are normally, independently and identically distributed with zero mean.

for 48 percent soybean meal prices are from the *Red Meats Yearbook* and the *Livestock, Dairy and Poultry Situation and Outlook*.[15] The data for sow price (κ) are from the *Red Meats Yearbook* (USDA/ERS, 2002). The one-year Treasury bond return issued by the Federal Reserve Bank of Dallas is used to represent the discount rate (r). This monthly series is made quarterly by taking the average of the monthly observations in the quarter. Data pertaining to the number of pigs per litter and the number of hogs on farm are from the *Hogs and Pigs Report* (USDA/NASS, 1970-2002). Finally, the producer price index for farm goods is used to deflate price variables and the data are taken from the U.S. Bureau of Labor Statistics.

Note the following details pertaining to the empirical specification and estimation of the model. First, with the exception of sow price, all the right-hand side variables are lagged by one period to account for a plausible lag between investment decision and realization. The current price of sow is utilized to reflect the fact that realized investment depends, in part, on the prevailing price of the capital at the time when the payment has to be made. Second, given that the dependent variable is in a first-difference form (i.e., current stock minus stock carried over from the previous period), a constant term is not included in the estimation. Third, the hog and feed prices enter the equation as a price ratio variable, rather than as two individual prices. Fourth,

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[15] The *Red Meats Yearbook* reports 48 percent soybean meal price for the period of 1979 through 1999, and the *Livestock, Dairy and Poultry Situation and Outlook* reports a 44 percent soybean meal price prior to 1979. To render the two series compatible, a simple linear regression of the 48 percent soybean meal price on the 44 percent price is run using data from1979 through 1999. The estimated relationship is then used to impute the price of 48 percent soybean meal for the periods prior to 1979 (i.e., the first quarter of 1976 to the last quarter of 1978).

to conserve degrees of freedom, only the parameter associated with the hog-feed price ratio is allowed to vary across the three regimes; other parameters are regime invariant.[16] Fifth, for the reason discussed in the section 3, the hog-feed price ratio is adopted in the empirical specification as the threshold variable separating the sample, rather than the hog price, ρ, as suggested by the conceptual equations in (7) - (9). Further, since one may intuitively argue that it is the change in the hog-feed price ratio from one period to the next that motivates producers to adjust their investment behavior, the variable that enters the empirical specification as the threshold variable is the current over the one-period lagged hog-feed price ratio.[17] Sixth, the equation is estimated in Gauss and the program code is modified from Hansen's code which is available at his website (http://www.ssc.wisc.edu/~bhansen/progs/progs.htm).

Table 1 reports the results pertaining to the determination of the number of thresholds, their estimates, and the associated confidence intervals. When comparing the null hypothesis of no threshold versus the alternative of single threshold, the result is ambiguous in that the null hypothesis can be rejected only at about the 85 percent confidence level (the likelihood ratio statistic for this test is 6.01 and the bootstrapped 90 percent critical value is 8.50). Given the ambiguity and in light of the low power of this likelihood ratio test when multiple thresholds exist, it is decided to proceed with the

[16] Hansen's procedures allow for a subset of the parameters to be regime invariant.

[17] The specification of the current over lagged price ratio also has the advantage that the estimated thresholds can readily be transformed to be time-varying by multiplying the estimated thresholds with the lagged price ratio and using the current price ratio as the threshold variable for sample separation. Rendering the thresholds time-varying in this way is conducive for analyzing data with long time series.

test of single-threshold versus double-threshold models.[18] With the likelihood ratio statistic being 12.85 for the second test and the bootstrapped 99 percent critical value at 12.04, the single-threshold null is decisively rejected in favor of the double-threshold (i.e., three-regime) model.

The estimated upper threshold is 0.9257 and the lower threshold is 0.8988 for the three-regime model. Given the magnitudes of the estimated thresholds, the associated confidence intervals reported in Table 1 are rather wide.[19] The estimated upper and lower thresholds are the two benchmarks against which the threshold variable is compared for sample separation. As previously mentioned, the threshold variable in the empirical model is the current over lagged hog-feed price ratio, which has a minimum value of 0.64 and a maximum of 1.58, with its median being 0.99. Thus, the estimated upper and lower thresholds fall below the median, but lie close to it, suggesting that there is ample opportunity for observations to fall outside of the sluggish regime and into the investment or disinvestment regimes. Out of a total of 95 quarters in the study period, 18 are in the disinvestment regime, 11 lie in the sluggish regime, and 66 are in the investment regime. While the investment/disinvestment

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[18] Bai notes that the test statistic used here is designed for a single threshold and, hence, has less power when the true model has multiple thresholds. As such, he argues that there may be marginal cases in which one wants to proceed with Test 2 even if the null hypothesis of no threshold is not rejected in Test 1.

[19] Note that the 95% confidence intervals for the estimated upper and lower thresholds overlap. If the two thresholds are indeed the same, the two-threshold model would reduce to a one-threshold model, a caveat that needs to be borne in mind. However, as reported, the likelihood ratio statistic strongly favors the two-threshold model, rejecting the one-threshold model at the 99% confidence level.

regimes predominate, the results indicate that the sluggish regime has occurred sufficiently often to warrant concern and attention.

Table 2 reports the estimated slope coefficients, the corresponding t-ratios, and other statistics. With the exception of a dummy variable, all the estimated parameters are statistically significant with expected signs. Regarding the regime-dependent coefficients of hog-feed price ratio, the estimates are positive for all three regimes and, consistent with expectation, the coefficient pertaining to the sluggish regime is much smaller in magnitude than those for the investment and disinvestment regimes. With regard to the regime-invariant parameters, the coefficient on the lagged breeding herd variable is positive and statistically significant. The adjustment rate of the associated linear accelerator is -0.027, which is obtained by subtracting the sow herd depreciation rate (0.1) from the coefficient of the lagged breeding herd variable (e.g., see Mundlak). This rate indicates an adjustment of about 2.7 percent per quarter (or 10.8 percent per year) toward the long-run equilibrium breeding stock. The negative coefficient associated with the sow price variable is consistent with the notion of a downward sloping quasi-fixed input demand, while the negative coefficient associated with the wage rate indicates that breeding herd and farm labor are complements. The coefficient on the Treasury bond rate is negative suggesting that additional investment in quasi-fixed input will occur if the discount rate decreases. The positive coefficient on the number of pigs per litter variable indicates that as the sow productivity improves, the producer has an incentive to increase the number of sows. The positive correlation between the overall industry capacity and the breeding herd size is reflected by the sign associated with the capacity proxy variable of the number of hogs on farm. Finally, the negative coefficient associated with the conditional standard deviations of the hog output prices corroborates the notion that price uncertainty will hinder output supply and, hence, quasi-fixed input investment.

As reported in Table 2, the R-square for the estimated three-regime model is 0.64, which is reasonable considering that the dependent variable is measured in first difference rather than in level. The in-sample Theil U statistic associated with the three-regime model is 0.11, suggesting again that the model fits the data reasonably well.[20] To gain insights into the issue of how the model would perform *ex ante*, the equation is re-estimated with data for the last 12 quarters reserved for the purpose of out-of-sample forecast performance evaluation.[21] Compared with the previous full-sample model, the coefficients in the re-estimated equation are found to be similar in magnitudes, signs, and statistical significance. The out-of-sample Theil U statistic is 0.15, demonstrating the model's ability in making adequate *ex ante* predictions.

The full-sample-estimated three-regime breeding herd investment demand equation will be used to investigate the effects on breeding stock and hog output supply of policy interventions of changing investment/disinvestment sluggishness. To obtain

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[20] Theil U statistic is a measure of root mean-square simulation error, normalized in such a way that the statistic falls between zero and one with zero indicating the simulated variable mimics exactly the observed variable and one indicating the predictive performance of the model is as bad as it possibly could be (Pindyck and Rubinfeld).

[21] Specifically, the newly re-estimated three-regime model is used to generate a series of one-step-ahead forecasts for the twelve reserved data points against which the observed data are compared. The values for the right-hand side variables are taken from the observed data when computing the out-of-sample forecasts.

the linkage between breeding stock and hog output supply, a hog supply equation, specified in part as a function of lagged breeding stock, is estimated in the next section.

Hog Supply Equation

Due to the biological lag in production, producers' decisions on how much to supply depend, among other factors, on the output price expected to prevail at the marketing date. Given the assumption of naïve price expectation, the two-quarter-lagged hog price is included in the model as a supply determinant.[22] To account for the effect on supply of capacity constraint and production inertia, the one-quarter-lagged supply also enters the equation as a right-hand side variable. Other explanatory variables include feed price, breeding stock, a linear trend, and seasonal dummy variables, all lagged two periods to account for the above mentioned biological lag. Similar to the specification in the breeding herd investment equation, the lagged hog and feed prices enter the model as a hog-feed price ratio. Note that, while the analysis treats the breeding stock as an endogenous variable via the investment demand equation, there is no need for an instrument here for the breeding stock variable as it enters the supply equation with a two-period lag. The trend variable is used to capture the effect on supply of gradual improvements in the hog finishing technology.

Quarterly data from 1976 through 1999 are used in the estimation, a sample period that is the same as that used in the estimation of the breeding herd investment demand

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[22] A two-quarter-lag specification is chosen because the average gestation period is 114 days (slightly less than four months), the average time in the nursery is three to eight weeks, and the average finishing time required is four to five months. The above biological relationship implies a six-month lag between farrow and finish.

equation. With the exception of the quantity of hogs, the data sources for the hog supply estimation are the same as those previously mentioned.[23] The estimation results are reported in Table 3. The R-square for the hog supply equation is 0.92, indicating an excellent fit of the model to the data. The Durbin-h statistic is -0.468 suggesting that the residuals are free from serial correlation, given the critical value of the normal distribution at the 5 percent level being 1.645 for a one-tailed test. The lagged dependent variable is highly significant and positive, lying between zero and one, which in turn, suggests that the dynamics of the supply are stationary and non-explosive. The coefficient on the breeding stock variable is significant and positive, confirming the existence of a link between the quasi-fixed input and hog supply. The lagged hog-feed price ratio is positive and significant, suggesting that as the expected output-input price ratio increases the supply increases. The coefficient on the trend variable is positive and significant, supporting the notion that there is a positive relationship between hog supply and finishing technology. All the seasonal dummy variables are statistically significant.

[23] The hog quantity variable is in million pounds and is calculated as $(Q_r /.774 + IM - EX) \div 1{,}000{,}000$ where Q_r is the retail weight pork quantity (in pounds), the coefficient 0.774 is the conversion factor between carcass and retail weight, and IM and EX are hog imports and exports, both measured in pounds of carcass weight. The retail weight pork quantity is derived by multiplying the U.S. population figures (U.S. Department of Commerce) by pounds of per capita pork consumption for which monthly data are available in the *Livestock, Dairy and Poultry Situation and Outlook Report*. The monthly figures are made quarterly by taking the average of the monthly observations in the quarter. The imports and exports of hogs are taken from the *Red Meats Yearbook*.

Elasticities and Policy Simulations

The estimated breeding herd investment demand equation can be concisely expressed as $I_t = f(K_{t-1}, X_t \mid \text{other demand determinants})$, where X_t denotes some of the investment demand determinants such as one-period-lagged hog-feed price ratio, one-period-lagged hog price risk term (i.e., squared root of the conditional variances), one-period-lagged wage rate, and current sow price. Upon making use of $I_t \equiv K_t - 0.9\, K_{t-1}$, this investment equation can be equivalently written as the following stock equation:

$$K_t = f(K_{t-1}, X_t \mid \text{other demand determinants}),$$

where the coefficient associated with K_{t-1} in the stock equation is the coefficient on K_{t-1} in the investment equation plus 0.9. The estimated hog supply equation can be expressed as

$$S_t = f(S_{t-1}, K_{t-2}, \text{hog-feed price ratio}_{t-2} \mid \text{other supply determinants}).$$

Note that both the stock and the hog supply equations are of a dynamic nature because of the inclusion as a regressor of the lagged dependent variable. Further, the two equations constitute a recursive system owing to the inclusion of the lagged breeding stock in the hog supply equation. This dynamic recursive system is used to simulate the short-run and long-run elasticities with respect to hog-feed price ratio, hog output price risk, wage rate and sow price. In this investigation, short run is defined as the effect on the variable in question that occurs before the dynamics associated with the lagged dependent variable comes into play. By extension, long run is defined as the time period after the equation dynamics have been exerted. Given the definition, the short-run effect on breeding stock is represented by the coefficient of the shocking variable and the short-run elasticity can be computed accordingly. The long-run elasticity on stock is this short-run elasticity divided by the coefficient associated with the lagged breeding herd in the stock equation. The elasticity computation is a bit more complex when it comes to the hog supply equation because there are direct and indirect effects on supply, with the indirect effect arising via the effect on stock of the shocking variable. However, the above methods of computing short-run and long-run elasticities still apply.

Table 4 reports the short-run and long-run elasticities on breeding stock and supply. The short-run stock elasticities of hog-feed price ratio range from a low of 0.06 in the sluggish regime to a high of 0.09 in the investment regime, and the long-run elasticities range between 2.20 and 3.25. A one-percentage increase in the standard deviation of the hog price would induce a reduction in stock of about 0.01 percent in the short run and 0.45 percent in the long-run. Although the short-run sow price elasticity on breeding stock is only about -0.05, the corresponding long-run elasticity is 35 times as large (-1.73). The short-run elasticity with respect to wage is -0.18 and the long-run figure is -6.45. The result that the breeding stock is rather inelastic in the short-run but elastic in the long-run is consistent with the notion that there exist adjustment costs and, hence, stock evolves gradually over time. Note that the demand elasticity for breeding stock is much larger with respect to the farm wage (a cross price) than with respect to the sow price (the own price), driving home the importance of labor input in the production of hog output.

With regard to the supply elasticities in Table 4, the direct effect of the hog-feed price ratio is 0.03. This direct price effect is the same regardless of the regime because the supply equation does not involve any threshold estimation. On the other hand, the indirect effect of the hog-feed price ratio on supply is regime dependent, ranging from 0.005 in the sluggish regime to 0.007 in the investment regime. Recall that the indirect effect on supply arises from the specification that the hog-feed price ratio is also a determinant of the breeding stock which affects supply. The long-run supply elasticity of the hog-feed price ratio is 0.19 for the sluggish regime and 0.20 for the investment and disinvestment regimes. Regarding the effects on supply of other shocking variables in Table 4, there is only an indirect effect because those shocking variables do not enter the supply equation. The supply elasticities with respect to hog price risk, sow price, and farm labor wage are -0.001, -0.004, and -0.002, respectively. Given that there are only indirect effects, the supply elasticities with respect to those shocking variables are still very small in the long-run, -0.006 for hog price risk, -0.021 for sow price and -0.009 for farm wage.

Policy Simulations

While the previous econometric results indicate that an explicit allowance for investment rigidity is important to the estimation of breeding herd investment demand, it is insightful to assess the extent to which the rigidity impedes adjustment. To this effect simulations are conducted under two alternative threshold specifications by modifying the estimated upper and lower thresholds. Specifically, the first scenario involves increasing the upper threshold and decreasing the lower threshold by an equal magnitude, such that the range of the sluggish regime doubles. The second scenario involves a total removal of the sluggish regime by setting equal the upper and lower thresholds at the midpoint of the estimated sluggish regime range. Results from the above "Doubling the Sluggish Regime" and "Removing the Sluggish Regime" scenarios are then compared against the baseline results, which are the predicted values of the dependent variables using the estimated recursive investment demand/hog supply system. Insofar as the investment rigidity is due to irregularities in the adjustment cost function, and that these irregularities have become more severe as the industry becomes more specialized, the effect of going from "Removing the Sluggish Regime" scenario to the baseline scenario can be thought of as the impact that has occurred during the past decades. By the same token, the effect of doubling the sluggish regime from the baseline can be regarded as the impact that might occur in the future as the industry continues its trend of increasing specialization in capital inputs.

The simulations are conducted for the whole sample, save the first three periods for the initial conditions of the lagged dependent variables. The results are presented in Table 5. Note that under the baseline scenario ten observations fall within the sluggish regime. By removing the sluggish regime, six of those ten observations fall into the investment regime, and the remaining four into the disinvestment regime. Compared with the baseline scenario, on the other hand, doubling the sluggish regime results in only four additional observations in the sluggish regime, with two from each of the investment/disinvestments regimes. As to the stock effects, the removal of the sluggish regime results in an increase in the breeding stock of 216,000 heads per quarter on average, or a 2.86 percent increase from the baseline. The corresponding average increase in supply quantity is 47 million pounds per quarter, or 1.21%. The effect of doubling the sluggish regime results in an average quarterly reduction in the breeding herd size of 78,200 heads (1.01%) and a reduction in the supply quantity of 16.5 million pounds (0.42%), compared with the baseline.

Note the following two insights. First, the effects on both the breeding herd size and supply quantity are not symmetric under the "Removing the Sluggish Regime" and "Doubling the Sluggish Regime" scenarios, although the two simulations involve an equal change in the magnitude of the sluggish regime, albeit in different directions. The effect of doubling the sluggish regime is about a third as large in magnitude as the effect of removing the sluggish regime, suggesting that the worsening of investment rigidity in the hog production sector as it continues its trend of increasing specialization in capital inputs will not be as significant as the change that has occurred in the past few decades. Second, the impact of changes in investment rigidity on breeding herd size and supply quantity are actually rather modest in both scenarios, ranging from 0.42 and 2.86 percent. While this finding sighs a relief from the policy perspective as no interventions appear to be needed, the econometric results clearly indicate that equation estimates will be biased if investment rigidity is not explicitly accounted for in the estimation.

Summary and Conclusions

As the U.S. hog production sector becomes more and more specialized, the importance of capital inputs in contributing to a greater amount of output has heightened. Given that the capital stock cannot be costlessly adjusted and that the associated adjustment cost function may exhibit certain irregularities arising from the existence of various cost asymmetries between investment and disinvestment, profit-maximizing producers may find themselves trapped within a range of prices in which it is neither worthwhile investing another unit of the capital nor profitable liquidating the existing ones. This paper addresses two issues related to the quasi-fixed input employment in the U.S. hog production sector: does an inaction or sluggish regime exist in the demand for quasi-fixed input, and, if so, to what extent has it impeded adjustment in quasi-fixed input stock and, hence, hog output supply toward the long-term equilibrium levels?

The conceptual framework is based on Abel and Eberly who unify the previous literature on investment rigidity and asset fixity by including the various adjustment cost idiosyncrasies contributing to the existence of an inaction/sluggish regime, alongside an investment regime and a disinvestment regime. Quarterly data from 1976 through 1999 are used to estimate the resulting three-regime investment demand equation and, due to data limitations, the analysis focuses solely on breeding sows as the quasi-fixed input. To account for the importance on breeding herd investment of both input and output prices, a hog-feed price variable is chosen as the threshold variable against which the estimated upper and lower thresholds are compared to separate the sample into investment, inaction/sluggish, and disinvestment regimes. The three-regime threshold estimation procedure recently advanced by Hansen is adopted. To provide a linkage between breeding herd investment and hog output supply, a hog supply equation, specified in part as a function of lagged breeding stock, is estimated by a least squares procedure. The dynamic recursive system of breeding herd investment demand and hog supply is then used to derive the short-run and long-run breeding herd demand elasticities and hog output supply elasticities with respect to such determinants as the hog-feed price ratio, hog price risk, sow price, and farm labor wage. In addition, the effects on breeding stock and hog supply of changes in the magnitude of investment rigidities are simulated.

The econometric results strongly support the three-regime breeding herd investment model over alternative specifications that preclude the inaction/sluggish regime. While the estimated upper and lower thresholds lie close to the median of the threshold variable, 11 observations, out of a total of 95, fall into the inaction/sluggish regime, indicating that this regime has occurred sufficiently often to warrant attention. The estimated adjustment rate toward the long-run equilibrium breeding stock for the associated linear accelerator is 2.7 percent per quarter or 10.8 percent per year. The existence of a linkage between lagged breeding stock and hog supply is confirmed by the results from the hog supply equation estimation. The econometric results thus indicate that it is important to account for investment rigidity when estimating breeding herd demand and hog supply. The econometric finding that investment rigidity does exist is further corroborated by the computed short-run and long-run elasticities of breeding stock and hog supply with respect to exogenous shocks. While the computed elasticities are very small in the short run, the long-run figures suggest elastic responses.

The simulation results indicate that the effects on breeding stock and hog supply of a 100 percent increase in the range of investment rigidity is only one-third the magnitude of those from a 100 percent reduction, suggesting that the future impact will not be as significant as what the hog production sector has experienced in the past decades. A more important simulation result is that, its econometric significance notwithstanding, the impact of investment rigidity has been rather modest, about 3 percent at most. From a policy perspective this is a relief as no interventions appear to be needed. However, bear in mind that the econometric results clearly indicate that estimates will be biased if investment rigidity is not explicitly accounted for in the estimation. Bear also in mind that the above policy conclusion should not be extended, without further evidences, to other sectors of the hog industry. For example, it is not unreasonable to surmise that investment rigidities in the pork processing sector may be nontrivial, given the intensity of capital specialization therein. Indeed, this may prove to be a fruitful direction for future research.

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Table 1: Threshold Test Results

Estimated Threshold

	Estimate	95% Confidence Interval
Upper Threshold	0.9257	0.9238 ~ 0.9672
Lower Threshold	0.8988	0.8409 ~ 0.9911

Test for Number of Thresholds

Null Hypothesis	**Alternate Hypothesis**	**Likelihood Ratio Statistic**	**Bootstrapped Critical Values**		
			99%	95%	90%
No Threshold	One Threshold	6.01	14.19	10.15	8.50
One Threshold	Two Thresholds	12.85	12.04	8.74	7.18

Table 2: Quasi-Fixed Input Investment Demand Estimation Results

Dependent Variable: Breeding Herd Investment $_t$ ($K_t - 0.9\ K_{t-1}$)

Explanatory Variables	**Coefficient**	**t-ratio**
Regime Dependent Parameter		
Hog-Feed Price Ratio $_{t-1}$		
Investment regime	73.5141	4.64
Sluggish regime	49.6189	3.08
Disinvestment regime	68.6908	3.95
Regime Independent Parameters		
Breeding Herd $_{t-1}$	0.7279	2.45
(Sow Price ÷ PPI) $_t$	-937.0704	-2.67
(Farm Labor Wage ÷ PPI) $_{t-1}$	-26214.331	-4.08
(One year Treasury Bond Return ÷ PPI) $_{t-1}$	-3022.0958	-2.87
Pigs per Litter Size $_{t-1}$	183.9139	3.19
Number of Hogs on Farm $_{t-1}$	0.6574	1.88
Hog Price Risk $_{t-1}$ (Conditional Standard Deviations)	-17.9697	-1.61
Seasonal Dummy 1 $_{t-1}$	19.7747	0.37
Seasonal Dummy 2 $_{t-1}$	209.3400	4.28
Seasonal Dummy 3 $_{t-1}$	-334.8384	-5.37
R-square	0.64	
In-sample Theil U Statistic	0.11	
Out-of-sample Theil U Statistic	0.15	

Table 3: Hog Supply Estimates

Dependent Variable: Quantity of Hogs Supplied

Explanatory Variables	**Coefficient**	**t-ratio**
Quantity of Hogs Supplied $_{t-1}$	0.8322	15.64
Breeding Herd $_{t-2}$	0.0378	1.86
Hog-Feed Price Ratio $_{t-2}$	11.6038	1.92
Linear Trend	2.5183	2.81
Seasonal Dummy 1 $_{t-2}$	50.5731	1.61
Seasonal Dummy 2 $_{t-2}$	449.7376	14.32
Seasonal Dummy 3 $_{t-2}$	-138.4036	-4.04
Constant	52.4769	0.20
R^2	0.92	
Durbin h	-0.4680	

Table 4: Elasticities at the Sample Mean

On Stock

		Short-Run	Long-Run
Hog-Feed Price Ratio	Investment Regime	0.0887	3.2499
	Sluggish Regime	0.05987	2.2003
	Disinvestment Regime	0.08288	3.0460
Hog Price Risk		-0.0124	-0.4543
Sow Price		-0.0472	-1.7337
Farm Labor Wage		-0.1756	-6.4521

On Supply

		Short-Run			Long-Run
		Direct	Indirect	Total	
Hog-Feed Price Ratio	Investment Regime	0.0276	0.0066	0.0342	0.2035
	Sluggish Regime	0.0276	0.0045	0.0320	0.1907
	Disinvestment Regime	0.0276	0.0062	0.0337	0.2009
Hog Price Risk		NA	-0.0010	-0.0010	-0.0055
Sow Price		NA	-0.0035	-0.0035	-0.0209
Farm Labor Wage		NA	-0.0015	-0.0015	-0.0090

Table 5: Policy Simulation Results

	Doubling the Sluggish Regime Scenario	Baseline	Removing the Sluggish Regime Scenario
Number of Observations in Each Regime			
Investment Regime	63	65	71
Sluggish Regime	14	10	
Disinvestment Regime	15	17	21
Effect on Breeding Herd Size and Hog Supply (compared with the baseline)			
Change in Breeding Herd Size, 1,000 heads	-78.2		216
(percentage change)	(-1.01%)		(2.86%)
Change in Hog Supply, 1,000,000 pounds	-16.5		47
(percentage change)	(-0.42%)		(1.21%)