Investment under Uncertainty and Dynamic Adjustment in the Finnish Pork Industry

by

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Abstract

The paper develops and estimates a generalized investment model of the firm, using dynamic dual approach. Optimal zero investments are allowed to arise either from generalized adjustment costs, uncertainty, or both. The results suggest that hog production technology exhibits both short- and long-run size economies. Environmental regulations are, therefore, going to play an increasingly important role in determining hog production costs and spatial concentration of the hog industry.

INVESTMENT UNDER UNCERTAINTY AND DYNAMIC ADJUSTMENT IN THE FINNISH PORK INDUSTRY

In 1995, after four years of intense political debate, Finland joined the European Union (EU) and adopted the Common Agricultural Policy (CAP). While the entire agricultural sector of Finland was affected by the change, impacts have been particularly severe in the pork industry. Prior to entering the EU, hog prices, production, and returns in Finland were highly regulated with domestic price supports maintained via strict import restrictions on pork combined with a licensing scheme that controlled domestic production. While these regulations increased domestic prices and returns, they also severely retarded the size, growth, and efficiency of Finnish hog farms. In 1995, for example, the average Finnish hog farm had only half the number of hogs of the average Danish hog farm, and average hog production costs were 20-30% higher in Finland than in Denmark (Agricultural Economics Research Institute; Statens Jordbrugs- og Fiskeriøkonomiske Institut).

After joining the EU in 1995, import restrictions on other member countries were abolished and the CAP pricing mechanism was introduced. The producer price for hogs in Finland fell immediately by about 50%. Production costs also fell as grain prices declined, environmental taxes on fertilizer were lifted, and sales taxes on inputs were removed. However, it is clear that the returns to producing hogs in Finland have declined dramatically, and domestic producers now face stiff competition from low cost producers in the rest of the EU.

The need for rapid structural adjustment in the Finnish pork industry raises a number of important economic and policy questions. First, what is the nature of long-run size economies in the industry, and can these size economies be exploited to make domestic producers competitive under the CAP? Second, how much expansion in farm size would be required to reduce average costs to competitive levels (and how much exit from the industry will this imply if total domestic production levels are to remain approximately unchanged)? Third, what is the nature of the adjustment process and are there particular frictions and rigidities that will hamper adjustment? The objective of this paper is to answer these questions by specifying and estimating a stochastic, dynamic, dual model of investment under uncertainty in the Finnish pork industry.

One of the innovations in this paper is that we combine irreversibility, uncertainty, and adjustment costs into a stochastic dual model of investment under uncertainty that is amenable to empirical estimation. The model allows explicitly for stochastic transition equations describing the evolution of state variables and is estimated using a panel of Finnish hog farms over the period 1977-93. The sample is endogenously partitioned into regimes of zero, positive, and negative investments. Then the decision rules are estimated using full information maximum likelihood. The econometric model has a similar structure to a censored Tobit model, and the results provide a number of important insights into the structural adjustment process currently taking place in the Finnish hog industry.

The Dynamic Investment Model

Finnish hog farmers are assumed to face a set of stochastic transition equations for exogenous state variables that follow geometric Brownian motion with drift:

$$\Delta Z = \mu(Z)\Delta t + Pv \tag{1}$$

where Δ indicates a small change, $\mu(\cdot)$ is a non-random function or drift parameter, t is time, P is a matrix satisfying $PP' = \Sigma$, and v is an i.i.d. normal vector satisfying $E(v) = 0$, $E(v_i v_j) = 0$ for $i \neq j$ and $E(v_i^2) = \Delta t$. The state vector $Z = (\ln Y, \ln W, \ln Q)'$ consists of the logarithms of output Y, variable input prices W, and rental rates on capital goods Q. The state variables are all functions of time but time subscripts have been dropped to simplify the notation. Firms are assumed to have rational expectations regarding the future evolution of the state vector Z.

The production process is characterized by a transformation function $F(X,Y,K,I) = 0$ where X is a vector a variable inputs, K is a vector of capital stocks, and I is a vector of gross investments in capital goods. The transformation function is augmented with gross investment to account for adjustment costs as scarce resources have to be withdrawn from production to install new capital stock (Lucas). The capital stock evolves over time according to:

(2) $$\Delta K = (I - \delta K)\Delta t$$

where δ is a diagonal matrix of constant depreciation rates.

Firms are assumed to be risk neutral and minimize expected discounted production costs over an infinite horizon, subject to transition equations for capital and for the exogenous state variables:

(3) $$J(Z_0, K_0) = \min_I E_0 \left\{ \int_0^\infty e^{-rt} C(Z, K, I)\, dt \right\}$$

subject to (1) and (2). Here r is a constant discount rate and $C(\cdot)$ is an instantaneous cost function given by

(4) $$C(Z,K,I) = \min_X \left\{ W^{\prime} X: \quad F(X,Y,K,I) = 0 \right\} + Q^{\prime}(U + \gamma)K$$

where U in the identity matrix and γ is a diagonal matrix with diagonal elements equal to zero when $I \leq 0$ and some non-zero value when $I > 0$. Notice that the way rental costs have been defined allows for a proportional expansion (or contraction) in rental cost when the capital stock is being increased ($I > 0$) as compared to the base case of a capital stock decrease ($I < 0$). The parameters in γ therefore capture the degree of asymmetry in investment response.

Using standard stochastic dynamic programming techniques, the Hamilton-Jacobi-Bellman (HJB) equation corresponding to (3) is,

$$rJ = \min_{I} \left\{ C + \nabla_Z J \mu(Z) + \nabla_K J(I - \delta K) + \frac{1}{2}[\mathrm{vec}(\nabla_Z^2 J)]'[\mathrm{vec}(\Sigma)] \right\} \tag{5}$$

where $\nabla_i J$ is the gradient vector of J with respect to i evaluated at (t_0, Z_0, K_0), $\nabla_z^2 J$ is the hessian matrix of J with respect to Z evaluated at (t_0, Z_0, K_0), and vec is the column stacking operator.

Dynamic Duality

Before we can specify a functional form for J and proceed with econometric estimation we need to identify the characteristic properties of the value function J. These characteristic properties for J are derived from the characteristic properties of C via the dual problem:

$$C = \max_{W,Q} \{ rJ - \nabla_Z J \mu(Z) - \nabla_K J(I - \delta K) - \frac{1}{2}[\mathrm{vec}(\nabla_Z^2 J)]'[\mathrm{vec}(\Sigma)] \} \tag{6}$$

Convexity and other restrictions on C then impose corresponding restrictions on J via (6).

Nonstochastic Transition Equations

First consider the standard case of nonstochastic transition equations for exogenous state variables. In this case $\mathrm{vec}(\Sigma) = 0$ and the last term on the right-hand-side of (6) drops out. Even in this case it is well known that the requirement that C be concave in (W, Q) imposes third-order curvature properties on J (Epstein and Denny; Luh and Stefanou). The conventional solution to this problem is to *assume* static expectations, $\mu(Z) = 0$, and that the shadow price of installed capital $\nabla_K J$ is linear in prices (W, Q). Then concavity of J in (W, Q) is sufficient to ensure that C will be convex in I and concave in (W, Q).

The assumption of static expectation has been relaxed slightly. For example, Luh and Stefanou have shown that if *all* first derivatives of the value function ($\nabla_Z J$ as well as $\nabla_K J$) are linear in prices (W, Q), and $\mu(Z)$ is convex, then concavity of J in (W, Q) remains sufficient to ensure that C is convex in I and concave in (W, Q) (see equation (6)). But while this allows certain kinds of expected growth or depreciation patterns in the exogenous state variables, firms are still implicitly assumed to know the future path of all state variables with complete certainty, so that changes in uncertainty do not alter the decision to invest.

Stochastic Transition Equations

In our model we allow explicitly for firm uncertainty about the future path of state variables. Hence, $\mathrm{vec}(\Sigma) \neq 0$ in (6) and the right-hand-side then contains second derivatives of J as well as first derivatives. This clearly exacerbates the problem of analyzing duality relations between J and C because the convexity properties of C now impose fourth-order curvature properties on J (see equation (6)). Nevertheless, it is clear that the Luh and Stefanou sufficient conditions ($\nabla_K J$ and $\nabla_Z J$ linear in prices, and $\mu(Z)$ convex) are also sufficient for the stochastic case studied here. The reason is that if $\nabla_Z J$ is linear then $\nabla_Z^2 J$ is a matrix of constants and the convexity properties of C then do not depend on the stochastic (last) term on the right-hand-side of (6). However, the Luh and Stefanou conditions are too restrictive for our case because they essentially cause the stochastic problem to revert to a nonstochastic one. To overcome this problem, and allow price and output uncertainty to influence investment decisions, we generalize the Luh and Stefanou sufficient conditions on J. In particular, we derive the following proposition, a proof of which is available on request.

<u>Proposition</u>: If (a) J is non-decreasing and concave in (W, Q)

(b) $\nabla_K J$ is linear in (W, Q)

(c) $\nabla_Z^2 J$ is linear in (W, Q)

(d) $\mu(Z)$ is non-increasing and convex in (W, Q)

then the dual cost function C defined by (6) is convex in I and concave in (W, Q).

The usefulness of our generalization is that it allows a shift in uncertainty to alter investment decisions while still generating fairly tractable decision rules for econometric estimation.

Data and Preliminary Analysis

The preceding stochastic duality model was applied to data on a panel of Finnish hog farms over the period 1976-1993. The panel is unbalanced with 275 total farms being used but only 23 of these participating in the program over the entire study period. Farm output was defined as a single aggregate output and there are three capital goods (real estate, machinery, and labor) and an aggregate variable input which is used as the numeraire.

There are 18 annual observations on the output and normalized rental price variables. To undertake a preliminary investigation of time-series properties of the data the logarithm of each of these series was fitted to an AR(2) model of the form:

$$\Delta z_t = \beta_0 + \beta_1 z_{t-1} + \beta_2 \Delta z_{t-1} + \epsilon_t \tag{7}$$

where $\Delta z_t = z_t - z_{t-1}$. Under the null hypothesis of Brownian motion without drift then $\beta_0 = \beta_1 = \beta_2 = 0$. The test of $\beta_2 = 0$ can be conducted using a standard t test (Hamilton). The evidence strongly supports this hypothesis in all of our series using a 5% significance level. Setting $\beta_2 = 0$ we then tested $\beta_0 = \beta_1 = 0$ using standard Dickey-Fuller tests. Results were unable to reject the null hypothesis of a unit root without drift, again using a 5% significance level.

Specification tests on this simple logarithmic random walk model indicated that it provided a good fit to the output and normalized rental price data.

Empirical Implementation

Empirical implementation of the model requires a choice of functional forms for $\mu(\cdot)$ and $J(\cdot)$ which are consistent with the properties in the above proposition and which is consistent with the data generating process for the exogenous state variables. The preliminary data analysis suggests that $\mu(Z) = 0$ (geometric Brownian motion without drift) is consistent with Finnish hog industry data on output and normalized rental rates over the sample period. For $J(\cdot)$ we follow Epstein and specify a second-order approximation of the form:

$$J(\cdot) = a_0 + [A_1^{\prime}\ A_2^{\prime}\ A_3^{\prime}] \begin{bmatrix} K \\ \ln Y \\ \ln Q \end{bmatrix} + \frac{1}{2}[K^{\prime}\ \ln Y^{\prime}\ \ln Q^{\prime}] \begin{bmatrix} B_{11} & B_{21}^{\prime} & 0 \\ B_{21} & B_{22} & B_{32} \\ 0 & B_{32}^{\prime} & B_{33} \end{bmatrix} \begin{bmatrix} K \\ \ln Y \\ \ln Q \end{bmatrix} + Q^{\prime} M^{-1} K \qquad (8)$$

where a_0 is a parameter and the A, B, and M matrices are made up of unknown parameters. With these assumptions on $\mu(\cdot)$ and $J(\cdot)$ we can differentiate J to obtain the decision rules to be estimated:

$$i_j = \frac{r}{q_j} M_j [A_3 + B_{32} \ln Y + B_{33} \ln Q] - \sum_{l=1}^{3} M_{jl}(1 + \gamma_l) k_l + (r - 0.5\sigma_j^2 + \delta_j) k_j \qquad (9.1)$$

$$\begin{aligned} x = {} & \alpha + A_2^{\prime} r \ln Y + A_3^{\prime} r \ln Q + (A_1^{\prime} + B_{21} \ln Y)(rK - \dot{K}) + K^{\prime} B_{11}(0.5 rK - \dot{K}) \\ & + 0.5 r [\ln Y^{\prime} B_{22} \ln Y + 2 \ln Y^{\prime} B_{32}^{\prime} (\ln Q - 1) + \ln Q^{\prime} B_{33} (\ln Q - 2)] \end{aligned} \qquad (9.2)$$

for j = real estate, machinery, and labor and x = the aggregate variable input. Here, i_j is the jth element of I, q_j is the jth normalized rental price, M_j is the jth row of M, M_{jl} is the jlth element of M, σ_j^2 is the variance of the logarithm of the jth rental price, δ_j is the jth depreciation rate, and α is an unknown constant parameter determined by the values of other parameters in the system.

The optimal decision rules in our model may have discontinuities as well as be asymmetric. For real estate and machinery we observe both positive and zero investments in the data set, but no negative investments. The zero investments result from optimal choice of inaction, not from censoring. Nevertheless, our statistical model for real estate and machinery investment coincides with a model for censored data and has the same structure as a censored Tobit model. The labor investment data, on the other hand, has both positive and negative observations, but no zeros. Thus, we model labor and the aggregate variable input assuming they are continuous and observed without limits. The full model is estimated using FIML assuming normally distributed errors.

Results

Estimation results from the full model are provided in table 1. The effects of uncertainty on investment are estimated by using a dummy variable to represent a one-time increase in uncertainty when Finland began negotiating to enter the EU in 1991 (table 1). The estimated dummy variable coefficients for real estate and machinery are both negative and significantly different from zero at the 5% level, indicating that an increase in rental price uncertainty for these assets reduces investment. On the other hand, the estimated effect of uncertainty on labor investment is positive and not significant at the 5% level, indicating that the labor investment decision does not respond to increased uncertainty.

Asymmetry in the demand for labor is measured by the γ_{labor} parameter (table 1). The estimated γ_{labor} parameter is negative and highly significant, indicating that labor adjusts more rapidly in the expansion phase than in the contraction phase. The null hypothesis of immediate full adjustment is soundly rejected using a likelihood ratio test. This indicates the presence of adjustment costs and slow adjustment to shocks.

The nature of adjustment costs can be investigated via the equality $\partial C/\partial i_j = -\partial J/\partial k_j$ for j = real estate and machinery. These $\partial C/\partial i_j$ values were estimated at -88.6 for real estate and -287 for machinery, indicating that adjustment costs are decreasing in the size of the investment. This suggests economies of scale in investment (larger investments lead to lower adjustment costs), as suggested by Rothschild (1971). A similar result holds for labor.

Following Fernadez-Cornejo et. al, the elasticity of scale is defined as $\partial \ln J/\partial \ln y$ which measures the proportional change in the discounted present value of the cost stream for a given 1% expansion in output, holding factor prices and rates constant. The elasticity of scale was estimated as 0.00026, suggesting that the discounted cost stream will only rise by 0.026% for every 1% increase in output. Thus, average costs are declining sharply and there are very strong returns to scale. While perhaps implausibly low, this estimate does suggest that there are strong, economically significant scale economies available in Finnish hog production.

Implications for Adjustment in the Finnish Hog Industry

The estimation results suggest that the Finnish hog industry is operating with strong increasing returns to scale technology. Increasing firm size will result in cost savings and more efficient utilization of farm capital and labor. Results also suggest that there are short-run scale economies in investment, such that the larger the investment the lower the adjustment costs that are realized. Together, these two results favor drastic, one-time expansions in firm size to achieve lower production costs, rather than slow, gradual adjustment. This is consistent with recent observations that most hog farms engaging in new investment are expanding their operations to the upper limits set by environmental regulations.

The elasticity of scale estimate of 0.00026 suggests that a 50% increase in farm size would decrease average costs by as much as 33%, enough to be competitive with Danish hog production. This 50% increase in farm size would require about one third of current producers to exit the industry if current industry output were to be maintained. The survey of Kallinen et. al. predicted that, as a result of Finland's entry into the EU, some farms will engage in new investment and increase their size by about 60%, while others would do nothing. Overall this would result in a 30 % increase in the average size of the production units. Even under the very strong increasing returns to scale estimated here, the predicted hog farm investments from Kallinen et. al. seem too small to fully adjust to the new market environment and reduce average costs to Danish levels. The recent observed adjustments taking place also suggest that the industry will not get competitive in the EU over the five year transitional period. In the first membership year of 1995 little hog industry investment took place, while in 1996 and 1997 the average size of Finnish hog production units has only increased by an average 8% per year, which would imply a 36 % increase in size by the end of the five year transitional period.

One of the major historical impediments to rapid adjustment appears to be excess labor in farming and an inflexible labor market. This suggests that the early retirement plans for existing hog farmers will play a key role in determining how the industry adjusts to EU entry.

While economies of size and adjustment policies in response to Finland's entry into the EU are pushing the industry towards expansion and larger farm sizes, environmental regulations which tie the maximum size of the hog operation to the farm's land area are working to limit the amount of expansion that can take place, particularly in some geographic areas. While these environmental regulations may be justified on health and welfare grounds there is a need for additional flexibility so that manure can be spread in the most appropriate locations without retarding incentives to expand farm size and reduce costs.

Conclusions

Existing dynamic dual models of investment typically assume investing firms know future state variable paths with complete certainty, and that investment decision rules are symmetric during capital expansion and contraction phases. Yet most state variables are more appropriately modeled as a stochastic process, and irreversibility and asymmetric adjustment costs may induce an asymmetric investment response. In this paper we derive a stochastic model of investment under uncertainty where firms perceive state variables as geometric Brownian motion with drift. Stochastic dynamic programming is used to characterize duality relations. We also allow for a shift in rental rates during capital expansion and contraction phases which introduces an asymmetry into the investment decision rules generated by the model.

The resulting model was applied to a sample of Finnish hog farms and it was found that real estate and machinery investments respond negatively to increases in uncertainty while labor decisions are insensitive to uncertainty. Labor investment is found to be asymmetric with contractions in labor usage adjusting more slowly than expansions. Economies of size were found for both output expansion and investment, suggesting that large one-time expansions are favored over slow gradual adjustment.

Table 1. Estimation Results

Parameter	Estimate	Standard Error	Parameter	Estimate	Standard Error
α	1.5697	0.0318	B_{33} (1, 1)	-7.6662	0.0000
			B_{33} (2, 1)	-1.0094	0.0000
A_1 (1, 1)	-0.0015	0.0199	B_{33} (3, 1)	3.6553	6.7022
A_1 (2,1)	0.8039	0.0444	B_{33} (2, 2)	5.2930	14.3623
A_1 (3, 1)	0.0441	0.0313	B_{33} (3, 2)	9.4346	8.5854
			B_{33} (3,3)	-8/3346	22.8756
A_2 (1, 1)	5.1028	2.9578			
			M (1, 1)	0.0366	0.0080
A_3 (1, 1)	0.6149	1.3652	M (2, 1)	-0.0073	0.0021
A_3 (2, 1)	13.7338	3.9852	M (3,1)	0.0142	0.0032
A_3 (3, 1)	-4.7171	4.2193	M (2, 2)	0.0059	0.0005
			M (3, 2)	0.0031	0.0018
B_{11} (1, 1)	-0.0035	0.0011	M (3, 3)	0.1103	0.0019
B_{11} (2, 1)	0.0140	0.0027			
B_{11} (3, 1)	0.0024	0.0008	γ_{labor}	-1.9517	0.1903
B_{11} (2, 2)	0.2126	0.0162			
B_{11} (3, 2)	-0.0113	0.0040	Weather dummy	0.0396	0.0205
B_{11} (3,3)	-0.0040	0.0017			
			$\Delta\sigma^2_{real\ estate\ rent}$	-0.0355	0.0174
B_{21} (1, 1)	0.0303	0.0230	$\Delta\sigma^2_{machinery\ rent}$	-0.0224	0.0025
B_{21} (2, 1)	-2.0026	0.0926	$\Delta\sigma^2_{wage\ rate}$	0.0201	0.0174
B_{21} (3, 1)	0.0852	0.0244			
			Number of observations = 1928		
B_{22} (1, 1)	7.7998	0.7920	Average log likelihood value = 1.353		
B_{32} (1, 1)	-1.1033	1.9741			
B_{32} (2, 1)	8.5731	3.3266			
B_{32} (3, 1)	-10.3699	1.9637			

Notes: Most of the parameter values refer to the parameter matrices defined in (9). For example, B_{11} (i, j) in the ijth element of the B_{11} matrix. The γ_{labor} value is the asymmetric response parameter in the demand for labor. The "weather dummy" is the coefficient on a dummy variable for poor crop years in the variable input demand equation. Finally, the $\Delta\sigma_i^2$ terms represent parameters on dummy variables allowing shifts in the variance of the relevant rental price when Finland began negotiating to enter the EU in 1991.

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