Staff Paper

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by

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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. Production licenses were generally not granted to enterprises desiring over 400 hogs, and each licensed farm had to have enough land to produce at least 40% of hog feed requirements (raised to 75% in 1984). 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.

A number of structural adjustment policies were implemented to assist the Finnish pork industry through this difficult transition. First, temporary direct income transfers were given to Finnish hog farmers to compensate them for the decline in hog prices and returns. Second, an early retirement scheme was introduced to encourage hog farmers to exit the industry. Third, an investment subsidy scheme was implemented to provide incentives for some producers to expand size and invest in more efficient production systems. Each of these policies is scheduled to be phased out over a five year adjustment period so that, at the end of the five years, Finnish hog producers will be expected to compete openly with producers from other EU countries.

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.

Investment, disinvestment, and changes in industry structure, are dynamic processes and their investigation requires a dynamic model. Firm expansions and contractions are influenced by two types of time-dependent frictions—adjustment costs and irreversibility (Lucas; Arrow; Abel and Eberly). Adjustment costs penalize rapid changes in a firm's capital stock, which results in investment smoothing over time and a potential discrepancy between actual and desired capital stocks (Lucas; Rothschild). Irreversibility may be caused by a wedge between acquisition and salvage values for industry or firm-specific assets, or because the adjustment cost function is kinked resulting in different adjustment costs for disinvestment than for investment (Arrow; Caballero; Dixit and Pindyck). If investments can be delayed, irreversibility makes them especially sensitive to uncertainty (Pindyck).

Uncertainty, irreversibility, and adjustment costs are of great importance in the Finnish pork industry which is going through a fairly drastic structural change. Investment frictions will delay and spread investment over time. More importantly, these frictions create entry barriers and protection by conferring cost advantages on early investors. Uncertainty, irreversibility and adjustment costs will, therefore, have considerable implications for the success of the Finnish hog industry as a new entrant into the EU. At present, however, we lack information about the extent of irreversibility and characteristics of the adjustment process on Finnish hog farms.

There have been numerous agricultural applications of dynamic dual investment models under convex adjustment costs (e.g. Vasavada and Chambers; Stefanou; Luh and Stefanou; Howard and Shumway; Taylor and Monson). While providing useful results, these models are essentially deterministic in that investing firms' are assumed to know the future path of exogenous state variables with certainty, even though these state variables evolve stochastically and are estimated with stochastic econometric models. Furthermore, existing empirical studies do not generally model irreversibility, in the sense that positive and negative gross investments are typically assumed to follow the same decision rule (for exceptions, see Chang and Stefanou; and Oude Lansink and Stefanou). Recent theoretical work has combined the notions of uncertainty, adjustment costs and irreversibility in a truly stochastic dynamic model that allows for stochastic transition equations for state variables (e.g. Pindyck; Chavas; Abel and Eberly). However, these models have not been applied empirically using a dual approach.

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. In particular, we develop methods for estimating a stochastic dual model where irreversible investment behavior is allowed to arise from generalized adjustment costs and/or from differences between acquisition prices and salvage values. 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

The model is based on dynamic intertemporal duality theory (McLaren and Cooper; Epstein; Epstein and Denny; Taylor). Major advantages of the dual approach are that it is straightforward to generate closed form decision rules in terms of underlying structural parameters, and restrictions on the production technology (such as independent adjustment rates) can be tested rather than imposed. Our dual model is constructed so that the instantaneous production technology is augmented by internal adjustment costs, as has been standard in the literature. But, in addition, we generalize the model to allow for uncertainty, irreversibility, and more general adjustment costs. Therefore, the model allows not only for investment smoothing but also for firm uncertainty over the future path of state variables and an optimal choice of inaction (zero investment).

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 assumption of an exogenous output level Y is appropriate for the Finnish hog industry over the sample period because output levels were strictly controlled by government policy via a licensing scheme. 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, but they also realize that the state vector follows a stochastic process and so uncertainty about future state vector values can influence investment decisions.

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.[1] 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:

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

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) $$C(Z,K,I) = \min_{X} \{ W'X\text{:} \;\; F(X,Y,K,I) = 0 \} + Q'(U + \gamma)K$$

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 ($I < 0$). This asymmetry in rental costs may be due to a difference between acquisition price and salvage values for capital goods, or to an asymmetry in the costs of adjusting the capital stock upward versus downward. 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,

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

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.

Assuming the integral in (3) converges, and some fairly mild regularity conditions on C, then the dynamic cost minimization problem will have a solution that is characterized by the HJB equation.[2] Furthermore, differentiating the HJB equation with respect to $\ln Q$ and $\ln W$, and using the envelope theorem, we get optimal decision rules in terms of the optimal value function and its derivatives:

$$
\begin{aligned}
\dot{K}^{*} &= (\nabla_{K,\ln Q}J)^{-1}\{r(\nabla_{\ln Q}J)' - (U + \gamma)K \odot Q - (\nabla_{Z,\ln Q}J)\mu(Z) \\
&\quad - [\nabla_{\ln Q}\mu(Z)]'(\nabla_{Z}J)' - \frac{1}{2}\nabla_{\ln Q}[\mathrm{vec}(\nabla_{Z}^{2}J)'\mathrm{vec}(\Sigma)]\}
\end{aligned}
\tag{6.1}
$$

$$
\begin{aligned}
X^{*} \odot W &= r(\nabla_{\ln W}J) - (\nabla_{Z,\ln W}J)\mu(Z) - [\nabla_{\ln W}\mu(Z)]'(\nabla_{Z}J)' \\
&\quad - (\nabla_{K,\ln W}J)\dot{K} - \frac{1}{2}\nabla_{\ln W}[\mathrm{vec}(\nabla_{Z}^{2}J)'\mathrm{vec}(\Sigma)]
\end{aligned}
\tag{6.2}
$$

where $\odot$ indicates element by element multiplication, $\dot{K}^{*}$ is the time derivative of the optimal capital path, and X^{*} is the optimal variable input vector. Given a functional form for the value function J and drift function μ, equations (6.1) and (6.2) can be used to derive closed-form decision rules that could be estimated econometrically.

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:

$$(7) \qquad C = \max_{W,Q}\{rJ - \nabla_Z J\mu(Z) - \nabla_K J(I - \delta K) - \frac{1}{2}[\mathrm{vec}(\nabla_Z^2 J)]'[\mathrm{vec}(\Sigma)]\}$$

Convexity and other restrictions on C then impose corresponding restrictions on J via (7).

Nonstochastic Transition Equations

First consider the standard case of nonstochastic transition equations for exogenous state variables. In this case $\mathbf{vec}(\Sigma) = \mathbf{0}$ and the last term on the right-hand-side of (7) 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). To see this, note that the first derivative of J appears on the right-hand-side of (7) so that second derivative properties on C impose third derivative restrictions on J. Thus, a complete characterization of the necessary conditions on J requires third derivative properties.

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). Therefore, a J which satisfies: (a) $J \geq 0$; (b) J concave in (W, Q); (c) $\nabla_K J$ linear in (W, Q); and (d) other minor regularity restrictions; is the value function for some cost function C under the assumption of static expectations, $\mu(Z) = 0$ (see Epstein and Denny).

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 (7)). 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, $\mathbf{vec}(\Sigma) \neq \mathbf{0}$ in (7) 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 (7)). Thus, a complete characterization of the necessary conditions on J in the stochastic case requires fourth derivative properties.

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 (7). 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 (all of the variance terms in the optimal decision rules (6.1) and (6.2) drop out so that price and output uncertainty have no impact on decision making). This is clearly too restrictive to be of much use in studying how investment responds to changes in uncertainty.

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 which is proven in the appendix.

Proposition: If (a) J is 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-decreasing and convex in (W, Q)

then the dual cost function C defined by (7) is convex in I and concave in (W, Q), as required by the characteristic properties of the cost function.

Notice that the Luh and Stefanou sufficient conditions under convex μ and $vec(\Sigma) = 0$ require $\nabla_Z J$ to be linear in (W, Q), while we only require $\nabla_Z^2 J$ to be linear and non-decreasing in (W, Q) in our stochastic model. In other words, we allow $\nabla_Z J$ to be quadratic rather than requiring linearity, as in Luh and Stefanou. 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. The restriction (d) on μ can be made with little loss of generality. For example, a stationary VAR process or differenced VAR process with unit roots estimated in the logarithms of prices satisfy the required restrictions on μ.

Overall, the regularity conditions on J in the stochastic case are comparable to those in the deterministic case. The only significant additional restriction required is condition (c) of the proposition, a condition which is weaker than that used in Luh and Stefanou in their deterministic model.

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 farm-level data were obtained from a sample of Finnish hog farms participating in the Agricultural Economics Research Institute (AERI) bookkeeping program. The panel is unbalanced with 275 total farms being used but only 23 of these participating in the program over the entire study period. The total number of cross-sectional and time-series observations in the entire sample is 1,928.

Farm output was summarized by a single output index incorporating crop and livestock production. The values of all outputs were aggregated together and then divided by the nominal price of pork to get a total output measure in pork equivalents. The sample consists of specialized hog farms so that, on average, hog revenues accounted for 79% of total revenue.

Three capital inputs were measured—real estate, machinery and labor. The value of real estate was computed as the aggregate value of land, production buildings, and drainage systems for each farm. Then a real estate quantity index was constructed by dividing aggregate real estate values by an index of real estate prices. The real estate price index is an aggregate divisia index using AERI data on price indices for land, buildings, and drainage. Similarly, machinery values for each farm were divided by an index of machinery prices to get an index measure of the amount of machinery available. We treat labor as a capital good because it is likely that adjusting the labor input in rural Finland involves substantial adjustment costs. Nevertheless, in the sample data labor inputs are observed only as a service flow (the number of hours of labor services used). Hence, this service flow is used as a proxy for the total amount of labor available (i.e. we assume labor is always used to capacity).

Rental rates for capital goods are computed from capital price indices using the relationship $Q = (r + \delta)S$ where Q is the rental rate and S is the price of capital.[3] The real estate and machinery price indices discussed earlier were used to construct rental rates for these assets, along with an appropriate constant discount rate and geometric depreciation rate. Because r and δ

are assumed constant, all of the variation in Q is driven by variation in S. In the case of labor, data on annual average wages paid to agricultural workers was used as the rental rate.

Four variable inputs—feed, fertilizer, fuel and electricity—were aggregated into a single variable input index that is used as the numeraire in the empirical model. For each farm, expenditures on the four variable inputs were aggregated and divided by a variable input price index to get an index of total variable input quantities used. The variable input price index is a divisia index constructed from separate AERI indices on each of these input price categories. Since the variable input is the numeraire, the rental rates for real estate, machinery, and labor were divided by the variable input price index for subsequent analysis.

All individual farm data were obtained from the AERI sample of bookkeeping farms. All other price and index data were obtained from the AERI database or from the Statistical Office of Finland. In the absence of the continuous data required to estimate the continuous time decision rules and transition equations we used the discrete approximations $\dot{Z} \approx Z_t - Z_{t-1}$ and $\dot{K} \approx K_t - K_{t-1}$. Data on gross investments were constructed using $I = \dot{K} + \delta K$ for an appropriate vector of constant geometric depreciation rates δ.

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:[4]

$$\Delta z_t = \beta_0 + \beta_1 z_{t-1} + \beta_2 \Delta z_{t-1} + \epsilon_t \tag{8}$$

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 other characteristic properties of J), and which is consistent with the data generating process for the exogenous state variables. The preliminary data analysis reported above 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 so the conventional assumption of static expectations, $\mu(Z) = 0$, is made in our empirical work. Note, however, that the model can accommodate more general processes for the state variables and we only assume static expectations because it is consistent with the estimated transition equations.

For $J(\cdot)$ we follow Epstein and specify a second-order approximation of the form:

$$J(\cdot) = a_0 + [A_1' \; A_2' \; A_3'] \begin{bmatrix} K \\ \ln Y \\ \ln Q \end{bmatrix} + \frac{1}{2}[K' \; \ln Y' \; \ln Q'] \begin{bmatrix} B_{11} & B_{21}' & 0 \\ B_{21} & B_{22} & B_{32} \\ 0 & B_{32}' & B_{33} \end{bmatrix} \begin{bmatrix} K \\ \ln Y \\ \ln Q \end{bmatrix} + Q'M^{-1}K \tag{9}$$

where a_0 is a parameter and the A, B, and M matrices are made up of unknown parameters. It is easy to verify that (9) is consistent with the value function properties derived in the above proposition. In particular, the zero restrictions in the B matrix ensure that $\nabla_K J$ in linear in Q; and simple differentiation shows that $\nabla_Z^2 J$ is linear in Q. Notice also that although we are allowing for a discontinuity between capital expansion and contraction phases in investment decisions, both J and $\nabla_K J$ are continuously differentiable in K, as required along the optimal capital path (Abel and Eberly).

With these assumptions on $\mu(\cdot)$ and $J(\cdot)$ we can differentiate J, substitute into (6.1) and (6.2), and rearrange to obtain the decision rules to be estimated:[5]

$$(10.1)\quad i_j = \frac{r}{q_j} M_j [A_3 + B_{32} \ln Y + B_{33} \ln Q] - \sum_{l=1}^{3} M_{jl}(1 + \gamma_l) k_l + (r - 0.5\sigma_j^2 + \delta_j) k_j$$

$$(10.2)\quad \begin{aligned} x = {} & \alpha + A_2' r \ln Y + A_3' r \ln Q + (A_1' + B_{21} \ln Y)(rK - \dot{K}) + K' B_{11}(0.5 rK - \dot{K}) \\ & + 0.5 r [\ln Y' B_{22} \ln Y + 2 \ln Y' B_{32}' (\ln Q - 1) + \ln Q' B_{33} (\ln Q - 2)] \end{aligned}$$

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. Notice from the decision rules that uncertainty about future state variable paths influences the decision to invest, and investment may respond asymmetrically during capital expansion and contraction phases. These equations are highly nonlinear but can be estimated using full information maximum likelihood methods.

The empirical model consists of four decision rules—investment in real estate, investment in machinery, investment in labor, and demand for the numeraire variable input. To fit the model the discrete approximation $\dot{K} \approx K_{t+1} - K_t$ is again used. We also assume that the errors from the decision rule equations are independent of the error terms in the transition equations, so that the two systems can be estimated separately.

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, although we still allow the labor investment rules to be asymmetric in the expansion and contraction phase (see equation (10)). Thus, the final estimation takes the form:

$$i_j = g_j(Z,K,\theta_j) + \epsilon_j$$

(11.1)
$$i_j = \begin{cases} i_j^* & \text{if } i_j^* > 0 \\ 0 & \text{if } i_j^* \leq 0 \end{cases}$$

$$(11.2) \qquad \dot{k}_L = g_L(Z,K,\theta_L) + \epsilon_L$$

$$(11.3) \qquad x = g_x(Z,K,\dot{K},\theta_x) + \epsilon_x$$

where j = real estate and machinery, $\dot{k}_L$ is the change in the labor input, $g_j(\cdot)$, $g_L(\cdot)$ and $g_x(\cdot)$ are functions given by (10), and θ_j, θ_L, θ_x are parameter vectors given in (10). The terms i_j^* refer to latent form investments that are uncensored but not observed.

The full model is estimated using full information maximum likelihood assuming normally distributed errors. The effect of a change in uncertainty surrounding exogenous state variables was included via a dummy variable which allowed a one-time shift in the variance of normalized rental prices in 1991, in response to the start of negotiations on Finland's entry into the EU. Another dummy variable was also included in the variable input demand equation to account for the effect of poor weather in exceptionally unfavorable harvest years. The optimization was carried out using the constrained maximum likelihood routine in GAUSS.

Results

Estimation results from the full model are provided in table 1. Symmetry of the B and M matrices was imposed rather than tested in order to make the model more tractable. Many of the estimated parameters are significantly different from zero using an asymptotic t-test and a 5% significance level. Furthermore, the R^2 values for the labor investment and variable input demand equations are 0.49 and 0.76, respectively. These are reasonable values given the panel data set used. Overall, the model seems to provide a reasonable fit to the data.

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. This is consistent with the idea of asymmetric adjustment costs for labor, with the cost of disinvesting being greater than the cost of investing.

The nature of the adjustment process can be investigated by putting the results in flexible accelerator form:

$$\dot{K} = N(K - \bar{K}) \tag{12}$$

where $\bar{K}$ is the steady state capital stock and N is a matrix of adjustment rates determined by the estimated M and γ_{labor} values. When investment in machinery, real estate and labor are all positive (expansion phase) then the estimated adjustment matrix is

$$(13) \qquad \hat{N} = \begin{bmatrix} 0.0124 & & \\ 0.0073 & 0.0431 & \\ 0.0135 & 0.0030 & 0.154 \end{bmatrix}$$

The null hypothesis of immediate full adjustment (diagonal entries of -1 and off-diagonal entries zero) is soundly rejected using a likelihood ratio test. Indeed, each of the diagonal entries is significantly greater than -1 at the 5% level, and each of the off-diagonal entries is significantly different from zero at the same 5% level. This indicates the presence of adjustment costs and slow adjustment to shocks. Nevertheless, the positive diagonal entries in $\hat{N}$ suggest continued investment in the face of capital stock levels above the steady state (explosive investment paths). This result may be explained by market failures in capital and labor markets which have limited some farmers' access to capital and labor while allowing other farms to expand.[6]

Because of the asymmetry in labor demand the adjustment matrix during the labor contraction phase will differ from that in the labor expansion phase. The estimated adjustment matrix assuming negative labor investment is:

$$(14) \qquad \hat{N} = \begin{bmatrix} 0.0124 & & \\ 0.0073 & 0.0431 & \\ -0.0142 & -0.0031 & -0.0613 \end{bmatrix}$$

Adjustment costs and slow adjustment to shocks continues to occur but labor usage now converges to the steady state (negative diagonal entry in the third row). The difference between current labor and steady state use would decline by only 27% over a five-year period.[7] This indicates a very slow adjustment process.

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 is a plausible result which suggests economies of scale in investment (larger investments lead to lower adjustment costs), as suggested by Rothschild (1971). Nevertheless, it should be noted that this result violates the sufficient condition for a minimum in the original optimization problem and so we must rely on necessary conditions. 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 rental 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 model estimation results suggest that the Finnish hog industry is operating with strong increasing returns to scale technology. Increasing firm size will result in labor savings and more efficient utilization of farm capital. 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 slower adjustment or maintaining current farm sizes. 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 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.

Despite this need for expansion in farm size, adjustment rates in the Finnish hog industry have historically been slow. Perhaps this is simply a result of historical production controls, protection, and regulation, and adjustment will be much more rapid now that Finland has joined the EU. Nevertheless, some restrictions on local labor and land markets which may continue to retard adjustment remain. Furthermore, increased uncertainty has been shown to reduce investment and slow down adjustment. This suggests that any public policies designed to facilitate adjustment should have very specific and clear implementation procedures so that they do not add to producer uncertainty.

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. However, estimation results also suggest that the labor and capital markets are closely linked so that subsidized investment in land and machinery can also play a rule in facilitating adjustment.

Overall, our results suggest that environmental concerns are going to play an increasingly important role in determining the future of the hog industry. 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. Without exploiting economies of scale it is clear that the Finnish hog industry will not survive Finland's entry into the EU.

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, and value function restrictions are comparable to those in much existing empirical work assuming deterministic state variable paths. 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, which is consistent with higher adjustment costs in the contraction phase than in the expansion phase. Economies of size were found for both output expansion and investment, suggesting that large one-time expansions are favored over slow gradual adjustment. These results have important implications for the Finnish hog industry as it adjusts to Finland's entry into the EU.

ENDNOTES

1. Standard regularity conditions on F are: (a) $F(\cdot)$ is continuous and twice differentiable; (b) $F(\cdot)$ is strictly increasing in Y and strictly decreasing in X, K, and the absolute value of I; and (c) $F(\cdot)$ is convex in I and X.
2. Regularity conditions on C are: (a) $C \geq 0$; (b) C is increasing in Y, decreasing in K, and increasing (decreasing) in I if $I > 0$ ($I < 0$); (c) C is convex in I and concave in (W, Q); and (d) C is positively linearly homogeneous in (W, Q). These properties are standard and come from (4) and the usual regularity conditions on the product transformation function F (Epstein and Denny 1983).
3. This relationship between Q and S is derived by assuming the current asset price is a continuously discounted sum of all future rents on the (depreciated) asset (see Epstein and Denny).
4. In the case of the output variable we undertook the preliminary analysis on annual average output across the firms, rather than testing each farm's output separately.
5. Because we have assumed a single variable input which is defined as the numeraire then it's decision rule in actually calculated by solving the HJB equation (5) for X, simplifying, and collecting terms.
6. Farmer access to credit was rationed over much of the study period due to regulations which set interest rates below market clearing levels and restricted credit approvals. In the land market there were also strict environmental regulations limiting access. Also, the labor market in Finland is such that farmers have little access to short-run hiring and must rely on long-term hiring contracts.
7. Calculated as $1 - (1 - 0.0613)^5 = 0.27$.

APPENDIX

Proof of the Proposition

We need to show that each term on the right-hand-side of (7) is convex in I and concave in (W, Q). Convexity in I is immediate by condition (b) of the proposition. Furthermore, the first term, rJ, is concave in (W, Q) by condition (a) of the proposition; and the third and fourth terms, $-\nabla_K J(I - \delta K)$ and $-0.5[vec(\nabla_z^2 J)]'[vec(\Sigma)]$, are both linear and concave in (W, Q) by conditions (b) and (c) of the proposition. Turning to the second term, $-\nabla_Z J\mu(Z)$, we note from conditions (a) and (c) of the proposition that $\nabla_Z J$ is non-negative and quadratic while $\nabla_Z^2 J$ is negative semidefinite; and from condition (d) that μ is non-increasing and convex. These conditions are sufficient to ensure that $-\nabla_Z J\mu(Z)$ is concave in (W, Q).

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 $\Delta\sigma^2_i$ 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.

References

Abel, A.B. and J.C. Eberly. "A Unified Model of Investment Under Uncertainty." *Amer. Econ. Rev.* 84(1994):1369-1384.

Agricultural Economics Research Institute. *Results of Bookkeeping Farms in 1995.* Research Report 220, AERI, Helsinki, Finland, 1997.

Arrow, K.J. "Optimal Capital Policy with Irreversible Investment," in *Value Capital and Growth*, (Papers in Honor of Sir John Hickes), J.N. Wolfe (Ed). Edinburgh: Edinburgh University Press, 1968:1-19.

Caballero, R.J. "On the Sign of the Investment-Uncertainty Relationship." *Amer. Econ. Rev.* 81(1991):279-88.

Chang, C.C. and S.E. Stefanou. "Specification and Estimation of Asymmetric Adjustment Rates for Quasi-Fixed Factors of Production." *J. Econ. Dyn. and Control.* 12(1988):145-151.

Chavas, J.P. "Production and Investment Decisions Under Sunk Cost and Temporal Uncertainty." *Amer. J. Agr. Econ.* 76(1994):114-127.

Dixit, A.K. and R. Pindyck. *Investment Under Uncertainty*. Princeton: Princeton University Press, 1994.

Epstein, L.G. "Duality Theory and Functional Forms for Dynamic Factor Demands." *Rev. Econ. Stud.* 8(1981):81-95.

Epstein, L.G. and M. Denny. "The Multivariate Flexible Accelerator Model: Its Empirical Restrictions and an Application to US Manufacturing." *Econometrica* 51(1983):647-673.

Fernandez-Cornejo, J. and C.M. Gempesaw, J.G. Elterich, and S.E. Stefanou. "Dynamic Measures of Scope and Scale Economies: An Application to German Agriculture." *Amer. J. Agr. Econ.* 74(1992):329-342.

Hamilton, J.D. *Time Series Analysis.* Princeton: Princeton University Press, 1994.

Howard, W.H. and C.R. Shumway. "Dynamic Adjustment in the US Dairy Industry." *Amer. J. Agr. Econ.* 70(1988):837-847.

Kallinen, A., E. Heikkilä and V. Aver-Hautamäki. "Adjustment of Finnish Hog Production in the EU." *Food and Farm Facts*, 1996.

Lucas, R.E. Jr. "Optimal Investment Policy and the Flexible Accelerator." *Inter. Econ. Rev.* 8(1996):78-85.

Luh, Y.H. and S.E. Stefanou. "Estimating Dynamic Dual Models Under Non-Static Expectations." *Amer. J. Agr. Econ.* 78(1996):991-1003.

McLaren, K.R. and R.J. Cooper. "Intertemporal Duality: Application to the Theory of the Firm." *Econometrica* 48(1980):1755-62.

Oude Lansink, A. and S.E. Stefanou. "Asymmetric Adjustment of Dynamic Factors at the Firm Level."*Amer. J. Agr. Econ.* 79(1997):1340-1351.

Pindyck, R.S. "Irreversibility, Uncertainty and Investment," *J. Econ. Lit.* 29(1991):1110-1148.

Rothschild, M. "On the Cost of Adjustment." *Quart. J. Econ.* 85(1971):605-622.

Statens Jordbrugs-og Fiskeriøkonomiske Institut. *Economics of Agricultural Enterprises 1995/96.* Serie B nr.80. Copenhagen, Denmark, 1997.

Stefanou, S.E. "Returns to Scale in the Long Run: The Dynamic Theory of Cost," *South. Econ. J.* 55(1989):570-579.

Taylor, C.R. "Stochastic Dynamic Duality: Theory and Empirical Applicability." *Amer. J. Agr. Econ.* 66(1984):351-357.

Taylor, T.G.. and M.J. Monson. "Dynamic Factor Demands for Aggregate Southeastern United States Agriculture." *South. J. Agr. Econ.* 17(1985):1-9.

Vasavada, U. and R.C. Chambers. "Investment in US Agriculture." *Amer. J. Agr. Econon.* 68(1986):950-960.