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INCORPORATING TECHNOLOGICAL CHANGE IN ECONOMIC RELATIONSHIPS: AN APPLICATION TO THE DEMAND FOR FORMULA FEED IN FRANCE*

by

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ABSTRACT

The use of a linear time trend as a proxy for technological change in economic relationships often leads to unsatisfactory econometric results. An alternative procedure based on variational parameter procedures is proposed and applied to the demand for formula feed, fed to hogs, in France. The need to incorporate the technological diffusion process provides the theoretical justification for the procedures used, while the empirical results are quite encouraging.

"Of the puzzles confronting economists, none is, perhaps, of greater significance than whether the phenomenon of technological change can be abstracted from econometric models" (Renshaw, p. 955).

"The use of time trends in economic models is normally regarded as an admission of ignorance" (Deadman, Ghatak, p. 1068).

As suggested by these quotations this paper deals with the problem of incorporating technological change in econometric estimates of economic relationships. The commodity chosen to illustrate our idea is the demand for formula feed, fed to hogs, in France. Although only one example is given it is hoped that the technique is sufficiently general that it can be used in other situations.

Economic theory suggests that the diffusion of new technology in agriculture has induced effects on the price level, efficiency of production and substitution patterns among commodities. In the formula feed industry the introduction of least cost feed mixing, increased awareness of animal nutrition among farmers, vertical integration and modern merchandising techniques have all served to expand the demand for formula feeds. Representing these diverse influences, by a simple linear trend variable, in a derived demand function for formula feed is clearly inappropriate because it ignores the fact that the market for formula feed does not, and can not, expand at a constant rate.

The differential rate of growth in the formula feed industry can nonetheless be incorporated in the derived demand function through the use of variational parameter techniques (Maddala). The use of these techniques is the subject of the rest of this paper.

The Problem

Equation (1) is a typical derived demand function for formula feed,[1/]

$$(1) \quad Q_t = A + B\,Y_t + C\,\frac{PY_t}{PQ_t} + D\ \mathrm{TIME} + \mu_t$$

where, Q_t is the demand for formula feed in t, Y_t is the production of livestock in t, PY_t is the price of livestock in t, PQ_t is the price of formula feed in t, and TIME is a linear time trend. A, B, C and D are parameters to be estimated and μ_t is a random error term with the normal properties.

In equation (1) the increasing use of formula feed by farmers is captured by shifting the derived demand curve to the right by D units each year. But in reality the adaption of new technology likely affects equation (1) in three ways: (1) as more and more farmers use formula feeds the quantity of formula feed used per pound of pork production will approach the average feed conversion ratio, i.e., the parameter B will vary depending on the degree of market penetration; (2) the price of formula feeds may fall relative to livestock prices resulting in more demand for formula feed; and, (3) the introduction of formula feeds may change the associated pork production function. Ideally econometric estimates of equation (1) should incorporate all three of these influences.

In the example chosen for this paper it is clear that the introduction of formula feed had no great impact on the input/output price ratio, while changes in the livestock production function are reflected by changes in livestock output. Hence, the major issue is how to accommodate the varying impact of livestock production changes on the demand for formula feed.

The basic question to be answered is what pattern does the "efficiency response" coefficient B follow during the transition period from where very few farmers use formula feed to a situation where nearly all farmers are using formula feed. If we assume the adaption of formula feed follows a normal diffusion process the penetration ratio will follow an S-shaped curve and this is mirrored by a varying relationship between the quantity of formula feed used and livestock output represented by B_t in equation (2). (Figure 1)

$$(2) \quad Q_t = A + B_t Y_t + C \frac{PY_t}{PQ_t} + \mu_t$$

At the beginning of the transition period, the number of farmers having adopted the new feed input is small and its use related to total livestock production is similarly small at B1. After complete adoption of formula feeds the relationship between feed inputs and livestock output is much higher at B1 + B2 and this number should reflect the average feed conversion ratio if market penetration has been complete.

The Model

Although there are a number of ways to incorporate the change in the parameter B_t, over time, only two are presented - the first uses a logistic varying parameter model and the second a modified version of the adaptive regression model developed by Cooley and Prescott, and Rosenberg.

The logistic function provides a good approximation to the S-shaped curve depicted in Figure 1 for the efficiency response parameter B_t, (equation 3).[2/]

$$(3) \quad B_t = \bar{B}1 + \frac{B2}{1 + e^{B3-B4*TIME}} + v_t,$$

where, $\bar{B}1$, B2, B3 and B4 are all greater than zero, and where $v_t = N(0, G^2_{v_t})$ and $COV(\mu_t, v_t) = 0$.

Substituting equation (3) into equation (2) gives the logistic form of the estimated equation.

$$(4) \quad Q_t = A + C \frac{PY_t}{PQ_t} + \bar{B}1\ Y_t + \frac{B2\ Y_t}{1 + e^{B3-B4*TIME}} + Y_t\ v_t + \mu_t$$

The penetration ratio (X_t) in equation (4) can be represented by (5).

$$(5) \quad X_t = \frac{1}{1 + e^{B3-B4*TIME}}$$

which approaches 1.0 as TIME $\rightarrow \infty$, and which shows that the penetration ratio is linked to B_t according to equation 6.

$$(6) \quad B_t = \bar{B}1 + B2\ X_t$$

Expressions (4), (5) and (6) have several interesting interpretations. First, following Griliches (p. 504), B4 and B3 are respectively, the rate of growth coefficient or acceptance rate, and the constant of integration which positions the curve on the time scale. Second, as time tends to infinity, the asymptote ($\bar{B}1$ + B2), or ceiling in Griliches terms, is roughly equivalent to the quantity of formula feed needed to produce another unit of pork. This ceiling level may decrease over time because of better animal production techniques, and this possibility has been investigated by Surry, but space limitations prohibit detailing the analysis. Third, the elasticity of feed demand (E_{gy}) with respect to changes in livestock production is given by (7),

$$(7) \quad E_{gy} = B_t * \frac{Y_t}{Q_t},$$

and should approach one as TIME $\rightarrow \infty$. This is the case because as long as the penetration rate is less than 1.0 the rate of growth in the demand for Q_t will be higher than the rate of growth in livestock production.

In the logistic model the coefficient B_t varys over time according to a prespecified pattern. Since we know the parameter B_t must reach an upper limit at the completion of the diffusion process any convergent parameter structure that allows B_t to converge towards an upper limit is an alternative model structure. Rosenberg has developed such an estimator and it is given by equation 8,

$$(8) \quad B_t = (1 - \lambda)\bar{B} + \lambda B_{t-1} + w_t \ .$$

In this model the coefficient λ is an adjustment parameter which must be between zero and one in order for the difference equation to converge. It can be seen that for $0<\lambda<1$, $B_t \rightarrow \bar{B}$, as $t \rightarrow \infty$.

This formulation differs from the logistic model in the sense that the adjustment path associated with B_t is best suited to represent the upper portion of the S-shaped curve in Figure 1. Thus, the period in which B_t becomes variable should be located on the S-shaped curve, and during the time period, where the rate of growth begins to increase at an increasing rate, i.e., below the inflection point.[3/] The penetration rate for this model can be approximated by $B_t/\bar{B}$.

Following Maddala and using the lag operator (L) the estimatable form of the second model is

$$(9) \quad (1-\lambda L)Q_t = (1-\lambda)A + (1-\lambda)\bar{B}\ Y_t + C(1-\lambda L)\frac{PQ_t}{PY_t} + (1-\lambda L)\mu_t + Y_t\ w_t$$

which can be rewritten as

$$(10) \quad Q_t = (1-\lambda)A + (1-\lambda)\bar{B}\ Y_t + C\frac{PQ_t}{PY_t} - \lambda C\frac{PQ_{t-1}}{PY_{t-1}} + \lambda\ Q_{t-1} + \mu_t - \lambda\ \mu_{t-1} + w_t\ Y_t$$

Hence the estimatable form of the adaptive model contains lagged dependent and exogenous variables and has an heteroscedastic and autocorrelated error term.

Estimation Procedures

The estimation of equations (4) and (10) is not a trivial problem given their complicated error structures. Consequently, several simplifying assumptions are made to allow estimation by least squares, with the intention of using more elaborate estimation procedures if the preliminary results are encouraging.

In equation (4) the heteroscedastic error term vanishes if it is assumed the relationship (equation 3) describing the parameter variation is deterministic rather than stochastic. With this assumption equation 4 can be estimated using nonlinear least squares.

In order to simplify the estimation of equation (10) the relationship describing the parameter variation (equation 8) is again assumed to be deterministic. In this case equation 8 is a first order difference equation whose solution is (Yamane, p. 331):

$$(11) \quad B_t = B_0 \lambda^t + (1-\lambda)\bar{B} \frac{(1-\lambda^t)}{(1-\lambda)}$$

or,

$$(12) \quad B_t = B6 * e^{t \text{ Log } \lambda} + \bar{B}$$

where, $B6 = B_0 - \bar{B}$

Replacing B_t in (2) by (12) gives a demand curve with a well behaved error term that can be estimated using nonlinear least squares,

$$(13) \quad Q_t = A + B6\, Y_t\, e^{t \text{ Log } \lambda} + \bar{B}\, Y_t + C \frac{PQ_t}{PY_t} + \mu_t.$$

Empirical Results

Table 1 contains various estimates of the demand for pork formula feed in France.[4/] The table includes the estimates of the logistics curve and the adaptive model discussed earlier as well as, for comparison purposes, an equation with no time trend and an equation with a linear time trend. Both of these equations have been estimated both with and without a correction for serial correlation. A comparison of the first four equations in Table 1, which employ a constant parameter specification, indicates tremendous parameter variation between equations. For example, the coefficient attached to the livestock production variable ranges from 2.8 in equation (4) to 8.9 in equation (1). Similarly the price coefficient ranges from -67.9 to 107.046.

The parameter estimates obtained from the logistic and adaptive models appear more reasonable, and with the exception of the price term, have large t values associated with them.

Table 2 shows the implied time path of B_t, the penetration rate and elasticity of feed demand with respect to pork production, from both models over time. In the adaptive model it has been assumed that the B_t parameter was constant until 1965, for reasons stated earlier. For the logistics model the coefficient increases from 2.59 in 1960 to 4.927 in 1977 as the penetration rate increases from 2.47 percent to 98.16 percent. Over the same time the elasticity has fallen from over 3 to just above one. All of these numbers appear reasonable based on a priori knowledge.

For the adaptive model the value of B_t is higher over the entire estimation period as is the associated elasticity, but in general the differences are not great, particularly during the latter part of the period.

Summary and Conclusions

The two models used in this paper illustrate a way to introduce technological diffusion processes into econometric relationships. On the basis of the empirical results obtained for the demand for formula feed, fed to hogs, in France it is believed that the utilization of varying parameter models can improve the specification of economic relationships. Nonetheless more work is clearly needed to: (1) relax the assumption of deterministic parameter variation; (2) try diffusion models other than the one used here, and (3) apply the technique to other commodities and situations.

TABLE 1: Estimates of the Demand for Pork Formula Feed, in France[1/]

A. Constant parameter without a time trend:

$$Q_t = -\underset{(-3.9)}{6489.8} + \underset{(11.3)}{8.9}\, Y_t + \underset{(.7)}{107.0}\, PY_t/PQ_t \qquad \text{(OLS)}$$

$\bar{R}^2 = .958$ DW = 1.15 SEE = 298.7 OBS = 21

$$Q_t = 1645.9 + 3.5\, Y_t + 50.2\, PY_t/PQ_t \qquad \text{(Cochrane-Orcutt)}$$

$\bar{R}^2 = .980$ DW = 1.68 RHO = .96 SEE = 188.1 OBS = 21

B. Constant parameter with a linear trend:

$$Q_t = -\underset{(-1.3)}{2850.9} + \underset{(2.4)}{4.7}\, Y_t + \underset{(2.3)}{96.4}\, TIME - \underset{(-.4)}{67.9}\, PY_t/PQ_t \qquad \text{(OLS)}$$

$\bar{R}^2 = .966$ DW = .89 SEE = 267.8 OBS = 21

$$Q_t = -\underset{(-2.7)}{3264.3} + \underset{(2.4)}{2.8}\, Y_t + \underset{(5.0)}{186.2}\, TIME + \underset{(.6)}{44.5}\, PY_t/PQ_t \qquad \text{(Cochrane-Orcutt)}$$

$\bar{R}^2 = .988$ DW = 1.98 RHO = .76 SEE = 157.5 OBS = 21

C. Logistic varying parameter:

$$Q_t = -\underset{(-1.5)}{1776.3} + \underset{(2.36)}{2.58}\, Y_t + \underset{(5.45)}{2.48}\, Y_t/(1 + EXP(\underset{(4.83)}{6.36} - \underset{(-4.99)}{.45}\, TIME)) + \underset{(1.08)}{80.2}\, PY_t/PQ_t$$

DW = 2.21 SEE = 115.9 OBS = 21

D. Adaptive varying parameter:

$$Q_t = -2102.8 - \underset{(-5.65)}{3.03}\, Y_t{*}EXP(TIME{*}Log(\underset{(3.78)}{.874})) + \underset{(8.18)}{5.88}\, Y_t + \underset{(.79)}{69.2}\, PY_t/PQ_t$$

DW = 1.41 SEE = 159.9 OBS = 21

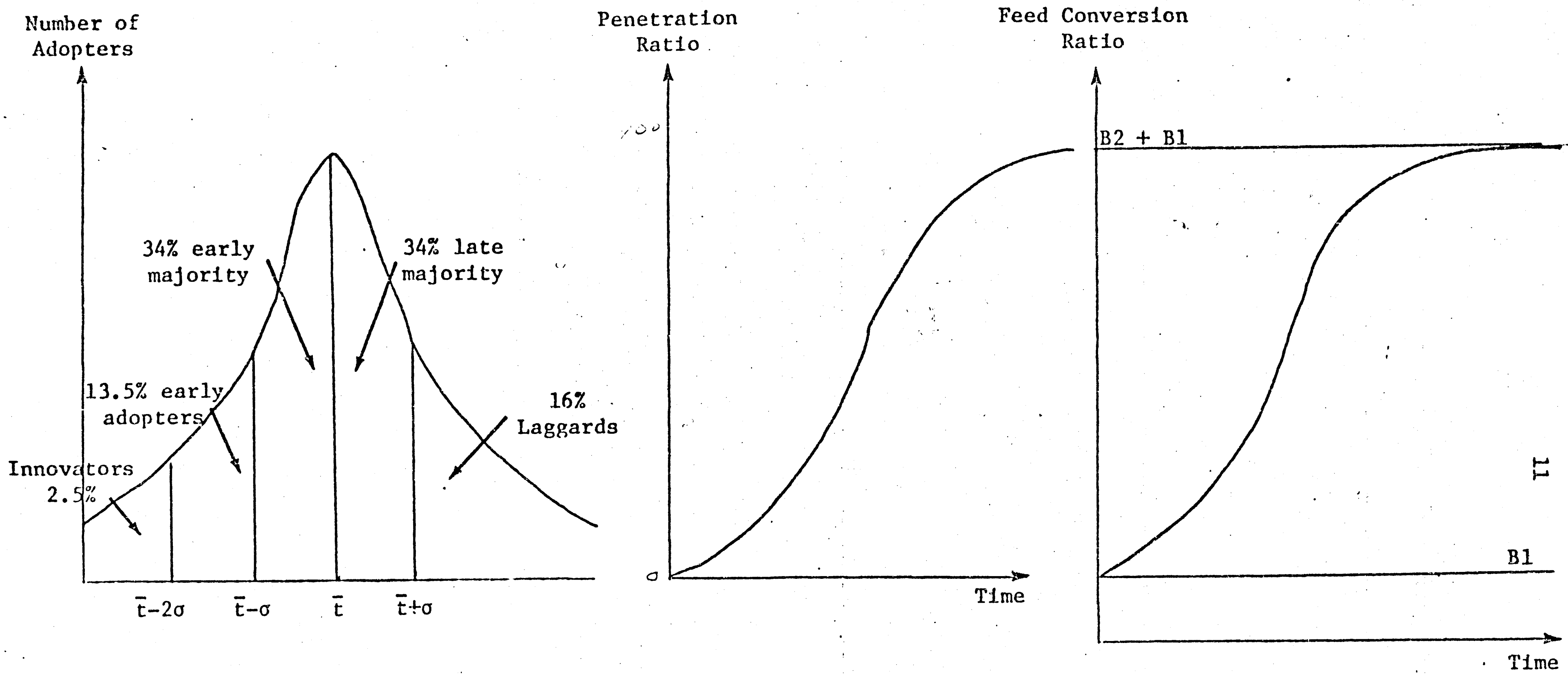
1/ t values given in parentheses.

TABLE 2: Estimated Values of Efficiency Response Coefficients, Penetration Rates, and Elasticity

	Logistic Model			Adaptive Model			Model With Time Variable (Cochrane Orcutt)
	B_t Fitted Coefficients	X_t Penetration Rate	E_{gy} Elasticity	B_t Fitted Coefficients	X_t Penetration Rate	E_{gy} Elasticity	E_{gy} Elasticity
1960	2.643	0.025	3.176	3.2349		3.887	3.1453
1964	2.914	0.133	2.027	3.2349	54.94	2.26	1.988
1968	3.7805	0.482	1.814	3.3953	73.71	1.629	1.159
1972	4.692	0.849	1.3755	4.984	84.66	1.461	0.865
1977	5.022	0.981	1.317	5.4266	92.18	1.424	0.747
Asymptote	5.068			5.88722			
λ				0.874			

E_{gy} = Elasticity of formula feed demand with respect to livestock production.

FIGURE 1: Normal Distribution Model of the Diffusion Process Applied to the Demand for Feed Formula



a) number of new adopters over time

b) evolution of the corresponding penetration ratio

c) expected evolution of the feed conversion ratio

Source: Adapted from Raj and Keller (p. 5)

FOOTNOTES

1/ The factor demand equation specified differs from the usual derived demand function in two respects. First, no substitutes for formula feed have been incorporated in equation (1) and, second, livestock production Y_t is considered a fixed factor and acts as a proxy for livestock inventories.

2/ It should be born in mind that the coefficient $\bar{B}1$, although related to B1, contained in Figure 1c, is not equivalent to the feed conversion ratio.

3/ The point where the rate of growth of the S-shaped curve begins to increase at an increasing rate is the first inflection point of the first derivative of this curve.

4/ All of the equations are estimated using annual calendar year data from 1957 to 1977.

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