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SIMULTANEITY OF TECHNOLOGY ADOPTION AND PRODUCTIVITY

By

Lydia Zepeda*/
University of Wisconsin-Madison

*/ Lydia Zepeda is an assistant professor in the Department of Agricultural Economics, University of Wisconsin-Madison. Gratitude is expressed to Professor Jean-Paul Chavas for his valuable comments on an earlier draft.

ABSTRACT

An adoption model is estimated to determine factors affecting the adoption of a record keeping system (DHIA) by California dairy farmers. Since productivity influences adoption of technology, a single equation adoption model to determine whether productivity affects technology adoption contains simultaneity bias. Thus, productivity and DHIA adoption are estimated as a mixed system of equations with continuous and discrete endogenous variables. Generalized Probit does not rid the system of simultaneity bias, so Heckman's two stage method is used. When the results are compared with biased single equation estimates, the implications are quite different. System estimates indicate that record keeping does indeed improve productivity, while productivity has no effect on adoption of record keeping. However, the biased single equation estimates indicate that productivity diminishes the adoption of record keeping.

Key words: technology adoption, simultaneous equation bias, probit analysis.

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Since Cochrane developed his treadmill model of technology adoption, many economists have examined how technological change has affected the structure of farming. Sociologists and economists have also looked at the adoption process in order to predict who might adopt the new technology and to determine, by default, who then might go out of business. Adoption models are used to test hypotheses on factors influencing technology adoption and to predict adoption based on those factors. Sociologists (Rogers; Rogers and Stanfield) have found that one variable associated with the adoption of a new technology is the productivity of the farmer. Feder and Slade use a regional measure of productivity of their ex post adoption model and find it is singificant in explaining the adoption of technology by rice farmers in northwest India. However, economic theory tells us technology affects productivity. So estimating a single equation ex post technology adoption model with productivity as an explanatory variable implies coefficient estimates are biased and inconsistent. Biased coefficient estimates diminish the power of technology adoption predictions, the implications of adoption patterns, and hypothesis testing on characteristics influencing technology adoption.

To test the effect of productivity on the ex post adoption of a technology, productivity and technology adoption must be estimated as a system of equations. In the following section, such a model is developed and econometric alternatives are examined to estimate the mixed system of discrete and continuous endogenous variables. Generalized Probit estimates are shown to be inconsistent and therefore cannot be asymptotically more efficient than Heckman's model as claimed by Amemiya (1978). The model is applied to test whether productivity does indeed effect the adoption of a record keeping system by milk producers. Biased single equation coefficient estimates are compared to the consistent systems estimates to see whether the implications and conclusions differ.

THE MODEL

Following McFadden, and Domenich and McFadden, who used Thurstone's random utility formulation, the following technology adoption model is constructed:

$$\text{(1)} \qquad \text{Max } \pi_i = \pi_i \, (Y_{1i} \, (W, X_{1i}), Y_{2i} \, (X_{2i}, Y_{1i}))$$

where π_i is the i^{th} individual's expected utility of the present value of profit which is a function of: Y_{1i}, the technology choices of the i^{th} individual; and Y_{2i}, the productivity of the i^{th} individual. Technology choice is in turn a function of the attributes of each technology, W, and the attributes of the individual, X_{1i}. Productivity is also a function of the attributes of the i^{th} individual and other explanatory variables, X_{2i} and the technology choice by the i^{th} individual, Y_{1i}. Equation (1) can be rewritten:

$$\text{(2)} \qquad \pi_i = \pi_i \, (Z_i \, (W, X_i, Y_i))$$

where Z_i is a function of the i^{th} individual's attributes, X_i; technology chosen, Y_i; and attributes of the technology, W. In the absence of a priori information on Z_i, a linear form, $Z_i = X_i\beta + Y_i \gamma + W\delta + \epsilon_i$ is used, where $\beta = (\beta_1 ... \beta_q)$. Assume ϵ_i is an error term that is independently, identically and normally distributed with mean zero. Let $Y_{1ij} = 1$ if the i^{th} individual chooses the j^{th} technology, and $Y_{1ij} = 0$ otherwise. Then, following Maddala, the probability of the i^{th} individual choosing the j^{th} technology is represented by a probit model. This model provides estimates of the conditional probabilities of technology adoption given the explanatory variables (Amemiya, 1981).

Since productivity and technology use are jointly determined, a simultaneous system of equations is implied. Productivity is a continuous variable, while a technology decision is a discrete choice. Simultaneous equation estimation of discrete and continuous endogenous variables may be accomplished with a two stage estimate such as Heckman's, Nelson and Olson's, or Amemiya's Generalized Probit model. The structural form of the system of equations is:

$$\text{(3a)} \qquad Y_{1j} = \begin{cases} 1 & \text{if } X_1\beta_1 + Y_2\gamma_1 + W_j\delta_j + \epsilon_1 > 0 \\ 0 & \text{otherwise} \end{cases}$$

$$\text{(3b)} \qquad Y_2 = X_2\beta_2 + Y_1\gamma_2 + \epsilon_2$$

where Y_{1j} and Y_2 are endogenous and Y_{1j} is a discrete variable, choice of the j^{th} technology, and Y_2 is a continuous variable, productivity. The X's and W's are exogenous variables, the betas, gammas and deltas are coefficients, and the epsilons are independent error terms.

The first stage estimates of the reduced form coefficients for (3a) and (3b) are:

$$(4a) \qquad Y_{1j} = \begin{cases} 1 & \text{if } X\pi_1 + u_1 > 0 \\ 0 & \text{otherwise} \end{cases}$$

$$(4b) \qquad Y_2 = X\pi_2 + u_2$$

where X is a matrix containing X_1, X_2 and W_j, the pi's are coefficients, and the u's are error terms. Y_{1j} is estimated with a probit model and Y_2 is estimated with ordinary least squares. The coefficient estimates, pi-hat, are used in the second stage to estimate structural form parameters. At this point we will compare Amemiya's Generalized Probit model with Heckman's model. The second stage estimates for Amemiya's Generalized Probit model are:

$$(5a) \qquad \hat{\pi}_1 = J_1\beta_1 + \hat{\pi}_2\gamma_1 + \eta_1$$

$$(5b) \qquad \hat{\pi}_2 = J_2\beta_2 + \hat{\pi}_1\gamma_2 + \eta_2$$

where the η's are error terms and the J's are matrices of zeros and ones such that $XJ_1 = X_1$ and $XJ_2 = X_2$. The Generalized Probit model uses $\hat{\pi}_1$ and $\hat{\pi}_2$ as regressors so the degrees of freedom are equal to the number of variables in X, k, minus the number of coefficients in (3a), k1, or (3b), k2, where k1 + k2 = k + 2. Thus, the degrees of freedom for (5a) are k - k1 or the number of coefficients in (3a) minus 2, and the degrees of freedom for (5b) are k - k2, or the number of coefficients in (3b) minus 2.

Several problems other than the degrees of freedom arise from this formulation. If (5a) and (5b) are estimated using generalized least squares as Amemiya recommends, the coefficient estimates of $\hat{\beta}$ and $\hat{\gamma}$ are biased and inconsistent. Equations (5a) and (5b) are a simultaneous system; $\hat{\pi}_1$ and $\hat{\pi}_2$ are both endogenous and explanatory variables. Lee's claim of consistency is based on a single equation estimate, not a mixed system. Therefore, Amemiya's claim (1978) that Generalized Probit estimates are asymptotically more efficient is unfounded, since they are not even consistent. System estimation of (5a) and (5b) by conventional two or three stage least squares estimates would not eliminate simultaneous equation bias. Reduced form estimates of pi double hat use J_i, $i=1,2$, a matrix of zeroes and ones as regressors. Therefore, pi double hat would equal the first k_i elements of pi hat and the structural form estimates using pi double hat as an instrument would still be biased and inconsistent.

Heckman's use of two stage least squares does overcome the simultaneity problem, as well as, the problem of estimating a system of equations with discrete and continuous endogenous variables. Parameter estimates of the reduced form (4a) and (4b) are used to predict the endogenous variables, $\hat{Y}_1$ and $\hat{Y}_2$. These are used as instruments in the structural form of the equations, overcoming the simultaneity problem.

$$\text{(6a)} \qquad Y_{1j} = \begin{cases} 1 & \text{if } X_1 \beta_1 + \hat{Y}_2 \gamma_1 + W_j \delta_j + e_1 > 0 \\ 0 & \text{otherwise} \end{cases}$$

$$\text{(6b)} \qquad Y_2 = X_2 \beta_2 + \hat{Y}_{1j} \gamma_2 + e_2$$

They result in consistent parameter estimates and therefore are asymptotically more efficient than Generalized Probit estimates. Hence, each structural equation can be estimated with the instruments using the appropriate discrete or continuous variable estimation procedure.

DATA

Data were collected in a telephone survey between August 10 and October 23, 1987 from 153 randomly selected California Grade A milk producers. The sample represents seven percent of the producer population in California. California is a suitable state for analysis of technology adoption because it has one of the nation's largest and most productive dairy industries. It is second in total milk production, and third in productivity per cow (USDA). Producers were asked structured questions about technology use, and characteristics of themselves and their farms. The response rate was 86 percent.

The technology choice examined is the adoption of a record keeping system by milk producers (DHIA). Choice of attributes (the X's) associated with technology adoption is guided by human capital theory, sociological research and other adoption models. Research by Nelson and Phelps, and by Wozniak show that education is a measure of human capital which reflects the ability to implement new technology. A survey by Feder, Just and Zilberman of models used to determine the factors influencing the adoption of agricultural innovations found farm size, risk, and human capital influence technology adoption. Size is associated with technology diffusion because returns to adoption are often greater in an absolute sense and the risk of adoption or experimentation is often less for a large firm.

Sociological research by Rogers and Stanfield, found previous farm productivity, farm size, farmer experience, education, and industry involvement associated with innovation. The association of productivity with technology diffusion may reflect a willingness of individuals to experiment with new technology since previous use resulted in higher productivity. Industry involvement is an indication of how receptive and well informed a manager is. Experience may be negatively or positively associated with technology adoption. Inexperienced farmers may have a longer planning horizon and may be less risk averse than, established farmers. However, farmers with experience may be better able to assess new technologies. Therefore, the hypotheses to be tested are whether farm size (COWS), productivity (PROD), education (EDUC), industry involvement (COWCLUB), and experience (YEARSOP)[1/] influence the adoption of record keeping.

Choice of the explanatory variables for productivity is guided by microeconomic theory. Productivity per cow is explained by the inputs used, management practices and environmental conditions. Environmental factors are represented by regional dummy variables (NC and SC); region influences production practices through climate, land prices, proximity to market, feed availability, etc. Management practices include: use of record keeping (DHIA) and three times a day milking (3X); and input usage is characterized by the pounds of concentrate fed per cow per day (FEED).

RESULTS

The software package LIMDEP was used to estimate the reduced form coefficients in equations (4a) and (4b) with the survey data. The coefficients are estimated by probit analysis and ordinary least squares, respectively. Predicted values of productivity (PROD) and record keeping (DHIA) are used as instruments to estimate equations (6a) and (6b) via probit analysis and ordinary least squares, respectively. The coefficients listed in Table 1 present estimates of these structural form coefficients. As expected, input use (FEED), regional environmental factors (NC and SC) and technology adoption (DHIA) enhance productivity. Three times a day milking (3X) is inversely related to productivity, though it is not a significant variable. This may be explained by the fact that it is not a widespread practice so there are few observations. The fact that the estimated effect on productivity is negative may explain why there are so few observations.

Experience (YEARSOP) is the only variable which is significant in explaining adoption of DHIA. Adoption of record keeping by producers seems to be inversely related to the number of years a producer has operated a dairy. Since DHIA has been around longer than most milk producers, it may indicate that in the later stage of a career the returns to record keeping may be small. More experienced milk producers may have established a production system that they are satisfied with, or they may have no need to expand production once they have reached a certain level of equity.

There is little statistical evidence that education (EDUC) and industry involvement (COWCLUB) have anything to do with the use of record keeping by dairy farmers. Size (COWS) and productivity (PROD) have no relationship with DHIA adoption, indicating there are no returns to scale for record keeping, with respect to farm size or productivity level.

To examine how single equation estimates may lead to different implications than the system estimates, Table 2 presents coefficients estimated by the single step method. Because theory tells us technology adoption affects productivity and we wish to ask whether productivity affects the adoption of a technology, single equation methods ignore the simultaneous system, giving biased coefficient estimates. The biased estimates would lead us to believe that only feed and region influence productivity, and that technology use does not affect productivity.

The factors explaining adoption of DHIA record keeping using single equation estimates still indicate that the number of years spent operating a dairy are inversely related to the adoption of the technology. However, education and industry involvement have a positive association with DHIA use, indicating a positive effect of extension or education programs on the adoption of record keeping systems. Productivity is negatively associated with adoption of record keeping in the single equation estimates, as opposed to the systems estimates which indicate that the relationship between record keeping and productivity is essentially zero. This implies that lower producing herds are more likely to use DHIA.

Thus, the implications are different under the two methods; adoption of DHIA record keeping has no influence on productivity for the single equation estimates, however once simultaneity bias is corrected, adoption of a record keeping technology does appear to influence productivity. Productivity appears to be negatively associated with DHIA adoption in the single equation biased model, and to have no relationship in the corrected model. Years operating a dairy influences adoption of DHIA record keeping for both models, however, education, farm size, and industry involvement are more strongly associated with DHIA adoption in the biased model than in the corrected model.

An implication of using a single equation estimation method to estimate adoption of a technology is that it can lead to incorrect conclusions concerning the factors affecting technology adoption. This underscores the importance of correcting for the simultaneous equation bias. For example, single equation estimates imply that extension education on DHIA record keeping would increase its use among California dairy farmers. However, since the technology has been around for 60 years, and farmers have had a chance to become acquainted with it, the implications of the system approach are more plausible. The system estimates imply that extension education would not increase the adoption of DHIA. Thus, implications drawn from single equation adoption models need to be reassessed.

IMPLICATIONS AND CONCLUSIONS

An adoption model is estimated to determine the factors affecting the adoption of a record keeping system (DHIA) by California dairy farmers. Theory tells us that productivity is influenced by the adoption of technology and many adoption models have included productivity measures to determine factors affecting technology adoption. Therefore, single equation estimates of a model of record keeping adoption contain simultaneity bias. Thus, productivity and DHIA adoption must be estimated as a system of equations to determine whether productivity does indeed affect the adoption of the record keeping technology. Generalized Probit methods developed by Amemiya to estimate a mixed system with continuous and discrete endogenous variables do not rid the system of simultaneity bias, however. Therefore, consistent Heckman two-stage methods are used to estimate the system. Since Generalized Probit estimates of mixed systems of equations are not consistent, one implication is that they cannot be asymptotically more efficient than Heckman's estimates as claimed by Amemiya.

Comparing the results of the consistent system estimates with the biased single equation estimates, leads to different implications. Consistent two stage estimates indicate that record keeping does indeed improve productivity, while productivity has no effect on the adoption of record keeping. The biased single equation estimates indicate education and industry involvement enhance record keeping adoption and productivity diminishes it. Thus, the bias introduced by single equation estimation methods leads to misleading implications about the factors influencing the technology adoption of record keeping. The example illustrates that failure to account for simultaneous equation bias in an adoption model could lead to incorrect policy implications concerning the factors that affect the adoption of a technology.

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ENDNOTES

1/ Age had no significant impact on the probability of adoption, either with experience or as a substitute for experience. Thus, the technology to which dairy farmers are exposed at the beginning of their career may be more influential than their planning horizon in determining technology use.

Table 1. Structural Form Coefficients of Productivity and Record Keeping Adoption (DHIA) Equations

	Coefficient	t-statistic
PRODUCTIVITY		
Feed Inputs	480.4	13.1
3X Milking	-1520.4	-1.3
Southern Region	1860.5	1.9
Northern Region	3713.5	5.5
DHIA	3674.9	3.8
DHIA		
Years Operating Dairy	-.0234	-2.4
Education Level	-.0544	1.3
Farm Size in Cows	.0002	0.5
Industry Involvement	.1889	1.3
Productivity	-.000005	-0.1

Table 2. Biased Single Equation Estimates of Productivity and Record Keeping Adoption (DHIA) Coefficients

	Coefficient	t-statistic
PRODUCTIVITY		
Feed Inputs	571.3	19.6
3X Milking	-1853.5	-1.5
Southern Region	2169.4	2.1
Northern Region	4256.6	6.1
DHIA	841.8	1.1
DHIA		
Operating a Dairy	-.02031	-2.2
Education Level	.08157	2.3
Farm Size in Cows	.00041	1.0
Industry Involvement	.24931	1.8
Productivity Level	-.00004	-1.2