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A Note on the Persistence of Firms' Innovation Behavior: A Dynamic Random Effect Probit Model Approach

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Abstract

Is firms' innovation behavior persistent? Using both patent and RDintensity as proxy variables of innovation and employing a new estimation method of the dynamic random effect probit model, this study finds a strong effect of state dependence after controlling for the firm heterogeneity. This result indicates that there is a causal effect from past innovation to current innovation, supporting the hypothesis of persistent innovation.

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1. Introduction

Innovation is a primary source of economic growth and industrial evolution. Importantly, are innovations contributed by firms of persistent innovating or a continuous renewal of innovating firms? This interesting issue has attracted widely interest for economists. Most theoretical literature suggest that firms' innovation behavior should be persistent,[1] while Aghion and Howitt (1992) take on the opposite view that technological change can be attributed to the process of creative destruction.

Despite the theoretical importance of this topic, there remains little systematic evidence on the question of innovation persistence at the firm-level (Geroski *et al.* 1997; Malerba and Orsenigo, 1999; Cefis and Orsenigo, 2001; Cefis, 2003; Duguet and Monjon, 2004). Overall, the existing studies conclude that firms' innovative persistence is rather weak, and that innovation is persistent in a small number of firms. The ambiguities and uncertainties remain in both theoretical and empirical literature, suggesting the need for further empirical works.

The aim of this note is to examine whether firms' innovation behavior is persistent by providing the following three distinct novelties. First, we employ a new estimator of the dynamic random effect (RE) probit model proposed by Wooldridge (2005) to empirically discuss this issue. Second, this study analyzes innovative persistence by focusing on both the output and input side of innovations, patent and R&D intensity. Third, benefited form the comprehensive information on firm-level data, this study can control for firm heterogeneity that influences firms' innovation behavior.

2. Empirical Framework, Econometric Method and Data

Different from the approach of previous studies, this paper uses the dynamic RE probit model to investigate that whether the innovation behavior is persistent at the firm level? If so, the observed persistent innovation comes from firm-specific characteristics or from the true state dependence? That is, whether there exists a causal effect that past innovation behavior itself enhances the probability of current innovation behavior?

Let a firm's innovation equation is defined as

$$INNO_{it} = \beta_0 + \rho INNO_{i,t-1} + \beta_1 SIZE_{it} + \beta_2 AGE_{it} + \beta_3 PROFIT_{it} + \beta_4 CR4_{it} + v_{it} \qquad (1)$$

where $INNO_{it}$ is a binary variable that equal 1 if firm i devotes to innovation behavior

[1] There are four streams of theoretical models, see Duguet and Monjon (2004) for a comprehensive review.

in year t. There are many possible ways to measure innovation. In this paper, we use both output and input index of innovations, patent and R&D intensity. If a firm has successful patent applications, $INNO_{it}$ equal 1. In terms of the input index, it is inappropriate to define INNO to equal 1 if a firm has positive expense on R&D, because it will throw away information by converting continuous data into a binary dummy. In order to consider the persistence on input-side of innovation, we therefore adopt the R&D intensity as an indicator and choose R&D intensity of 1.14% that was the mean R&D intensity of manufacturing sector in 1997 as the critical value.[2]

As for the independent variables, $INNO_{it-1}$ is the measure of state dependent, representing a firm's innovation behavior in year t-1. Importantly, the coefficient for this variable is we concern that it is used to indicate whether past innovation is significantly related to current innovation. A positive relationship can be evidenced the persistence of a firm's innovation, whilst a negative impact represents the extinction of innovative opportunity (Crepon and Duguet, 1997).

The size of the firm (*SIZE*) is measured as the number of employment. Large firms usually have noteworthy advantages in supporting R&D. They also enjoy economies of scale in generating patents due to the operating cost of maintaining a legal department to deal with intellectual property issues. However, Audretsch and Acs (1991) argue that small firms tend to outweigh large firms in innovation performance in a more technology-intensive environment. Term *AGE* is a firm's age and it is adopted to capture the learning-by-doing effect on innovation. Because the financing of innovation is widely studied in previous literature,[3] the firm's profitability (*PROFIT*) is also included. Finally, an industry-specific factor, CR4, is included. It is measured as the four-firm concentration ratio of the 3-digit electronics industry that a firm belongs to, representing the market structure where a firm lives.[4]

Because the dependent variable is a binary variable and the data includes both cross and time dimensions, a dynamic probit model is employed in this study. However, there are econometric problems must to be dealt with in this model: the (unobserved) individual effect and the initial condition for dynamic model. We therefore employ a new estimator of the dynamic RE probit model recently developed by Wooldridge (2005) to implement the estimation.

Therefore, the empirical framework can be specified as:

$$\begin{aligned} INNO_{it} = \beta_0 + \rho INNO_{i,t-1} + \beta_1 SIZE_{it} + \beta_2 AGE_{it} + \beta_3 PROFIT_{it} + \beta_4 CR4_{it} \\ + \beta_5 INNO_{i0} + \beta_6 ASIZE_i + \beta_7 AAGE_i + \beta_8 APROFIT_i + \beta_9 ACR4_i + u_{it} \end{aligned} \quad (2)$$

[2] We also used 2.54% that was the mean R&D intensity of electronics industry in 1997 as the critical value and experienced the similar results.
[3] The importance of financing on firms' R&D, please see Hall (2002) for a comprehensive survey.
[4] There are six three-digit electronics industry according to Taiwan's standard industrial classification of version 2001.

where $INNO_{i0}$ denotes the firm's innovation in the initial period. Terms *ASIZE*, *AAGE*, *APROFIT*, and *ACR4* represent the average value of the firm's size, age, profitability, and four-firm concentration ratio of the industry a firm belongs to over the surveyed period, respectively.[5] According to Wooldridge's (2005) specification, the variables for average value of firm- and industry-specific characteristics are employed to control for the unobserved individual effect and their estimated coefficients do not contain meaningful economic implications.

The dataset used in this study is a panel data of 246 electronics firms listed on the Taiwan Stock Exchange during the 1998-2003 period. The information for R&D and firm-specific characteristics are drawn from the company's annual financial statements and the patent data is drawn from Taiwan's Intellectual Property Office. The market structure variable is calculated by the authors. The variable definition and basic statistics are shown in Table1.

Table 1 Variable Definition and Basic Statistics

Variables	Definition	Mean (S.D.)
INNO		
PAT	Dummy Variable. PAT=1 if a firm has issued patents.	0.534 (0.499)
RD	Dummy Variable. RD=1 if a firm's R&D intensity is greater than 1.14%.	0.787 (0.410)
SIZE	The number of employees	984.0 (1753.2)
AGE	The firm's age. Surveyed year minus the starting year.	16.939 (8.126)
PROFIT	The firm's post-tax profitability. (%)	5.374 (41.987)
CR4	Four firm concentration of 3-digit electronics industry (%)	0.421 (0.155)

3. Empirical Results

Table 2 shows a series of estimates. Columns (1) and (3) are specified as the basic models that don't deal with the initial condition problem in dynamic probit model with unobserved heterogeneity. We can clearly that the coefficient for one-year lag innovation is positive and significant at 1% statistical level, implying that the electronics firms' innovation behavior is persistent in Taiwan. Moreover, the coefficients for $INNO_{i,t-1}$ are also significant larger than one, tending to reveal an dynamic increasing return to innovation.

[5] Wooldridge (2005) assumes that the unobserved individual effect depends on the initial condition and strict exogenous variables.

Table 2 The Estimates for Dynamic Random Effect Probit Model

Dep. Var.	PAT		RD Intensity	
Indep. Var.	(1)	(2)	(3)	(4)
INNO_1	1.574***	0.504***	2.289***	1.443***
	(0.087)	(0.166)	(0.109)	(0.167)
SIZE	0.3E-03***	0.5E-03***	0.1E-03**	0.2E-3
	(0.5E-04)	(0.16E-03)	(0.5E-04)	(0.2E-03)
AGE	-0.008	0.295***	-0.015**	0.095*
	(0.005)	(0.052)	(0.007)	(0.056)
PROFIT	0.002	0.002	0.003**	0.004**
	(0.14E-02)	(0.002)	(0.001)	(0.002)
CR4	0.518**	1.451	0.452	-1.272
	(0.289)	(1.349)	(0.363)	(0.432)
Individual Heterogeneity				
$INNO_0$		1.719***		1.328***
		(0.256)		(0.221)
ASIZE		-0.1E-03		-0.1E-3
		(0.17E-03)		(0.1E-3)
AAGE		-0.558***		-0.119**
		(0.176)		(0.058)
APROFIT		-0.6E-04		0.0004
		(0.12E-02)		(0.002)
ACR4	-0.919***	-0.687		1.902
	(0.147)	(1.382)	-0.728***	(0.259)
CONS		-0.984***	(0.198)	-0.807***
		(0.251)		(0.306)
σ_a		0.750		0.694
		(0.128)		(0.080)
ρ		0.360		0.325
		(0.079)		(0.051)
Obs.	1230	1230	1230	1230

Figures in parentheses are standard deviations. ***, ** and * denote coefficient significant at 1%, 5% and 10% statistical level, respectively.

Applying for the remedy proposed by Wooldridge (2005) to correct the unobserved heterogeneity and initial condition problem, the estimates of dynamic RE probit model are displayed in columns (2) and (4). The coefficient of $INNO_{i,t-1}$ is still positive and significant at the 1% statistical level, giving a piece of evidence for the persistence of innovation at the firm-level.

With respect to observed characteristics, the positive and significant coefficients for *SIZE* and *AGE* represent that a firm with a larger scale or an older firm tend to have a higher propensity on innovation, while the impacts of *PROFIT* and *CR*4 are not significant.

One problem of the dynamic RE probit model is that it assumes that explanatory variables must be strict exogenous, implying that there is no feedback effect caused from innovation to further value of explanatory variables. To assess the impact of including variables that perhaps fail the strict exogeneity assumption on the estimate for state dependent variable, we apply for stepwise procedures to check the robustness of the hypothesis of persistent innovation. A serial estimates are summarized in Table 3.

Table 3 Robustness of Estimates for the Dynamic Random Effect Probit Model

	PAT			
	(5)	(6)	(7)	(8)
INNO_1	1.224***	0.494***	0.488***	0.504***
	(0.101)	(0.165)	(0.165)	(0.166)
SIZE	0.49E-03***	0.45E-03***	0.46E-03***	0.5E-03***
	(0.12E-03)	(0.16E-03)	(0.16E-03)	(0.16E-03)
AGE		0.323***	0.292***	0.295***
		(0.045)	(0.052)	(0.052)
PROFIT			0.34E-02**	0.002
			(0.16E-02)	(0.002)
CR4				1.451
				(1.349)
Individual Heterogeneity				
$INNO_0$	0.780***	1.715***	1.749***	1.719***
	(0.117)	(0.254)	(0.257)	(0.256)
ASIZE	-0.3E-03***	-0.1E-03	-0.1E-03	-0.1E-03
	(0.1E-03)	(0.1E-3)	(0.17E-03)	(0.17E-03)
AAGE		-0.335***	-0.316***	-0.558***
		(0.047)	(0.054)	(0.176)
APROFIT			0.27E-04	-0.6E-04
			(0.12E-03)	(0.12E-02)
ACR4				-0.687
				(1.382)
CONS	-0.835***	-0.674***	-0.695***	-0.984***
	(0.061)	(0.171)	(0.176)	(0.251)
Obs.	1230	1230	1230	1230

Figures in parentheses are standard deviations. ***, ** and * denote coefficient significant at 1%, 5% and 10% statistical level, respectively.

Table 3 Robustness of Estimates for the Dynamic Random Effect Probit Model (continued)

	RD Intensity			
	(9)	(10)	(11)	(12)
INNO_1	1.475***	1.44***	1.453***	1.443***
	(0.168)	(0.167)	(0.167)	(0.167)
SIZE	0.0002	0.0001	0.0001	0.0002
	(0.0001)	(0.0001)	(0.0001)	(0.0002)
AGE		0.071*	0.067	0.095*
		(0.043)	(0.117)	(0.056)
PROFIT			0.004**	0.004**
			(0.002)	(0.002)
CR4				-1.272
				(0.432)
Individual Heterogeneity				
$INNO_0$	1.296***	1.306***	1.327***	1.328***
	(0.223)	(0.221)	(0.221)	(0.221)
ASIZE	-0.0001	-0.0001	-.00001	-0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
AAGE		-0.094**	-0.089**	-0.119**
		(0.044)	(0.044)	(0.058)
APROFIT			0.0004	0.0004
			(0.002)	(0.002)
ACR4				1.902
				(0.259)
CONS	-0.911***	-0.547**	-0.583**	-0.807***
	(0.144)	(0.226)	(0.229)	(0.306)
Obs.	1230	1230	1230	1230

Figures in parentheses are standard deviations. ***, ** and * denote coefficient significant at 1%, 5% and 10% statistical level, respectively.

Using patents and R&D intensity dummies as dependent variables, the stepwise estimates are displayed in columns (5)-(8) and (9)-(12), respectively. All the estimates are quite similar that the coefficient for lagged innovation variable is positive and significantly related to current innovation conditional on observed and unobserved characteristics. This finding lends support view of the persistence of innovation behavior. While the impact of past innovation on current innovation behavior decreases as more explanatory variables are included. In addition to past innovation behavior, firm size and age again play as crucial influences on innovation behavior.

One point worth noting is that the initial condition is also highly significant in all estimates, implying a substantial relationship between firms' initial innovation status and the unobserved heterogeneity.

4. Conclusion

This paper provides new evidence on the persistence of innovation at the firm level. Different from previous studies, we have examined persistence from both output and input sides of innovations. Employing a new estimator of the dynamic RE probit model proposed by Wooldridge (2005), the econometric results confirm the status of state dependence. This finding can be considered as giving support to the existence of persistent innovation after controlling for firm heterogeneity.

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