Success breeds success: the dynamics of the innovation process

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The Dynamics of the Innovation Process

by

Gebhard Flaig and Manfred Stadler

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1. Introduction

Technological progress is driven by major and minor innovations as results of endogenous innovative activity. Firms devote resources to their R&D labs in order to invent better or new products and processes. According to various hypotheses discussed in the literature, the amount of innovative activity should depend on elements of market structure as well as on demand and cost expectations of firms. Most empirical studies, analyzing the determinants of innovative activity, take a Schumpeterian view and relate innovative input and output measures to elements of market structure (see e.g. the surveys by Baldwin, Scott 1987, Cohen, Levin 1989, Acs, Audretsch 1990). Some alternative studies focus on the production structure of firms in considering innovative activities as investment in a stock of firm specific technological knowledge and relate these investments to the input prices of the production factors and to the stocks of the quasi-fixed factors (see e.g. Mohnen, Nadiri, Prucha 1986, Buck, Stadler 1992). However, only few studies take a wider view and try to simultaneously account for production and market structure effects based on decision theoretic optimization models of innovation (see König, Zimmermann 1986, Zimmermann 1989, König, Pohlmeier 1990, Pohlmeier 1992, Laisney, Pohlmeier, Lechner 1992). Even highly sophisticated, these models still lack in dealing with the dynamics of the innovation process. The purpose of the present paper is to take a further step towards an adequately dynamic econometric analysis of the firms' innovative behavior. Using a stochastic dynamic optimization model we derive an estimation function where innovations depend not only on market structure conditions and demand and cost expectations but also on unobserved heterogeneity of firms and on past realized innovations. The inclusion of lagged innovations allows us to test the hypothesis whether a success in innovation breeds further success indicating structural state dependence in the innovation process.

The paper is organized as follows. In Section 2 a stochastic dynamic optimization model is developed, explaining the firms' optimal levels of innovative activity in terms of past realized innovations, expected demand and supply conditions, and unobserved heterogeneity. Section 3 presents the econometric framework we use to empirically evaluate the various determinants of innovative behavior. Since we have dichotomous variables for realized product and process innovations, we apply a bivariate dynamic random effects probit model. A description of our panel data set and the empirical results are presented in Section 4. Section 5 finally contains some concluding remarks.

2. A Stochastic Dynamic Optimization Model of Innovative Activity

We assume that each firm maximizes its present value of profits over an infinite time horizon by choosing an optimal path of innovative activity. The innovation value π_t is the discounted stream of quasi rents flowing from Y_t innovations in period t, given Y_{t-1} realized innovations in the previous period. π_t is assumed to be concave in Y_t, i.e. $\partial^2\pi_t/(\partial Y_t)^2<0$. A special feature of our model is to take into account that, due to dynamic spillover effects, innovative success in the previous period is increasing the marginal value of the current period's innovations, $\partial^2\pi_t/(\partial Y_t \partial Y_{t-1})>0$. This effect is compatible with the "success breeds success" hypothesis discussed by Mansfield (1968) and Stoneman (1983). They argue that innovative success confers advantages in the technological opportunities that make further success more likely. The cost of an innovation, g, is assumed to be constant. Thus, discounting future innovation values with the factor δ, a firm maximizes its expected intertemporal profit function

$$(1) \qquad J_t = E_t \sum_{\tau=0}^{\infty} \delta^{\tau} \left[\pi_{t+\tau}(Y_{t+\tau}, Y_{t+\tau-1}) - g\, Y_{t+\tau} \right]$$

where E_t is the conditional expectations operator, given all available information at decision time t. In order to derive an explicit solution we adopt a quadratic specification for the innovation values

$$(2) \qquad \pi_{t+\tau} = \tilde{a}_{t+\tau} Y_{t+\tau} - (b/2)\, Y^2_{t+\tau} + c\, Y_{t+\tau} Y_{t+\tau-1} .$$

Variations of the variable $\tilde{a}_{t+\tau}$ lead to parallel shifts of the marginal value of an innovation. We will endogenize this variable within our econometric specification. The coefficients b and c are assumed to be positive and constant over time. Differentiating the profit function (1) with respect to innovative activity, using (2), yields a system of second order linear difference equations. According to these Euler equations the optimal innovation levels must satisfy

$$(3) \qquad E_{t+\tau} \left[a_{t+\tau} - b\, Y_{t+\tau} + c\, Y_{t+\tau-1} + c\, \delta\, Y_{t+\tau+1} \right] = 0 , \qquad \tau = 0, 1, 2, \ldots .$$

The sign of the variable $a_{t+\tau} \equiv \tilde{a}_{t+\tau} - g$ depends on the relative magnitudes of rents and costs of realizing an innovation. To solve the system of Euler equations (3), we need the historically given initial level of Y_{t-1} and the transversality condition as necessary conditions for optimality. It is assumed that $Y_{t+\tau}$ and $a_{t+\tau}$ are known with certainty in period $t+\tau$. Using the shift operator L, defined as $L^{-j} E_t Y_{t+\tau} \equiv E_t Y_{t+\tau+j}$, we can rewrite (3) as

$$(4) \qquad (c\, \delta L^{-2} - b L^{-1} + c)\, E_{t+\tau} Y_{t+\tau-1} = - E_{t+\tau} a_{t+\tau} .$$

To explicitly solve (4) we seek the factorization

$$(L^{-2} - b(c\delta)^{-1} L^{-1} + \delta^{-1}) = (\lambda_1 - L^{-1})(\lambda_2 - L^{-1}) . \tag{5}$$

Comparing powers of L yields

$$b(c\delta)^{-1} = \lambda_1 + \lambda_2 , \quad \delta^{-1} = \lambda_1 \lambda_2 . \tag{6}$$

Substituting either for λ_1 or for λ_2 in (6) gives

$$b/c = \delta \lambda + \lambda^{-1} . \tag{7}$$

The function $\delta \lambda + \lambda^{-1}$ has a minimum at $\lambda = \delta^{-0.5}$, attaining a value of $2\delta^{0.5}$ there. Under the condition $b > 2c\delta^{0.5}$ there are two real and distinct roots of (7). Denoting the smaller root by λ_1 and the larger root by λ_2, it can be shown that $0 < \lambda_1 < 1 < \delta^{-1} < \lambda_2$ holds. If the success breeds success hypothesis does not hold, λ_1 converges to zero, i.e. $\lim_{c \to 0} \lambda_1(c) = 0$. However, if it turns out that the econometrically estimated coefficient λ_1 is significantly positive, the hypothesis is supported. Using the factorization (5), we can write the difference equation (4) as

$$(\lambda_1 - L^{-1})(\lambda_2 - L^{-1}) E_{t+\tau} Y_{t+\tau-1} = -(c\delta)^{-1} E_{t+\tau} a_{t+\tau} . \tag{8}$$

To satisfy the transversality condition, we divide by the "forward" inverse of $(\lambda_2 - L^{-1})$ to get after some manipulations using the specifications (6)

$$(\lambda_1 - L^{-1}) E_{t+\tau} Y_{t+\tau-1} = [\, c^{-1} \lambda_1 / (1 - \lambda_2^{-1} L^{-1}) \,] E_{t+\tau} a_{t+\tau} . \tag{9}$$

Solving (9) for $\tau=0$, we obtain the explicit solution equation

$$Y_t = \lambda_1 Y_{t-1} + c^{-1} \lambda_1 \sum_{k=0}^{\infty} (\delta \lambda_1)^k E_t a_{t+k} . \tag{10}$$

This solution expresses current innovative activity as a function of once-lagged innovation, representing the success breeds success hypothesis, and current and future expected values of the determinants of marginal innovative value, representing some Schumpeterian hypotheses. For our empirical analysis we assume that these determinants split into observable variables, x_t, unobserved firm characteristics, ε, and a shock term, u_t. We assume that current but not future shocks are known to the firm at the decision time, i.e. $E_t u_t = u_t$ and $E_t u_{t+\tau} = 0$ for $\tau > 0$. For simplicity we use the linear specification

$$a_t = \alpha_1' x_t + \alpha_2 \varepsilon + u_t . \tag{11}$$

According to various Schumpeterian hypotheses, we assume that the observable determinants are summarized in the vector $x = (S, SH, H, H2, Q, W)'$ including firm size, S, market share, SH, market concentration, H, squared market concentration, H2, expected demand, Q, and expected labor cost, W. The variable ε represents all unobserved firm specific characteristics like creativity, intuition, appropriability of innovation rents and technological opportunities. This latent variable is constant over time and known to the firm. For simplicity we assume that firms have static expectations about the future market conditions x. Then it is straightforward, by inserting (11) into (10), to derive

$$(12) \quad Y_t = \lambda_1 Y_{t-1} + \beta' x_t + \varrho \varepsilon + u_t$$

with $\beta = \alpha_1 c^{-1} \lambda_1 / (1-\delta\lambda_1)$ and $\varrho = \alpha_2 c^{-1} \lambda_1 / (1-\delta\lambda_1)$. Equation (12) will serve as our basic innovation function. We will specify and estimate it for product innovations as well as for process innovations.

So far we modeled product and process innovations as separate decision variables. However, there could exist some spillover effects from product to process innovations and vice versa. To account for this possible interdependence, we have to solve the optimization problem (1) and (2) for a simultaneous two equation system. Therefore we generalize our model along the lines suggested by Sargent (1987, ch. IX) to

$$(13) \quad J_t = E_t \sum_{\tau=0}^{\infty} \delta^{\tau} [a'_{t+\tau} Y_{t+\tau} - (1/2) Y'_{t+\tau} B Y_{t+\tau} + Y'_{t+\tau} C Y_{t+\tau-1}]$$

with $Y_{t+\tau} = (Y_{t+\tau,1}, Y_{t+\tau,2})'$ where $Y_{t+\tau,1}$ and $Y_{t+\tau,2}$ denote the levels of product and process innovations, respectively. The time varying (2x1) vector $a'_{t+\tau}$ depends on the observable and unobservable determinants of product and process innovations. B and C are positive-definite (2x2) matrices and correspond to the coefficients b and c of the single equation model. The maximization of (13) with respect to innovative activity devoted to product and process innovations can be solved in the same way as before. The solution functions for product and process innovations are now dynamically interrelated and take the form

$$(14) \quad Y_{t,j} = \sum_{l=1}^{2} \lambda_{j,l} Y_{t-1,l} + \beta'_j x_{t,j} + \varrho_j \varepsilon + u_{t,j}, \quad j=1,2 .$$

It can be shown that the cross terms $\lambda_{j,l}$, $j \neq l$, equal zero only if both matrices B and C are diagonal. But in general, product and process innovations depend not only on their own lagged values, but also on cross lagged values. It seems to be reasonable, for example, that product innovations induce process innovations in the following periods. In our econometric investigation we will analyze both the univariate and the bivariate versions of the model. Since the univariate model is a special case of the bivariate model we will only present the econometric framework for the latter case.

3. Econometric Specification of the Bivariate Dynamic Random Effects Probit Model

In this section we discuss the econometric framework we will use to analyze the firms' dynamic innovative behavior over a period of several years. In our data set innovative activities Y are only observed as dichotomous variables, Y^D, indicating whether or not a firm has successfully implemented at least one product or process innovation. Our econometric model is based on the assumption that innovations are realized, if and only if the unobserved optimal level Y exceeds a threshold $\tilde{Y}>0$. This threshold can be rationalized by the existence of fixed cost in undertaking an innovation. According to our theoretical model, Y depends on lagged endogenous variables Y_{-1}, observed exogenous variables x, unobserved firm characteristics ε, and the shock u. This model allows us to distinguish between true structural dynamic interrelationships among the variables representing the innovation process and firm heterogeneity which may produce spurious correlation over time. The basic statistical model was developed by Heckman (1981a). In this paper it is extended to the case where two dependent discrete variables are observed in each time period.

Let $Y_{i,t,1}$ be the unobserved continuous variable representing the optimal level of product innovations for a firm i in period t and $Y_{i,t,2}$ the optimal level of process innovations for the same firm. If $Y_{i,t,j} \geq \tilde{Y}_j$, j=1,2, a firm realizes innovations of type j, if $Y_{i,t,j} < \tilde{Y}_j$, the firm decides not to innovate in the current period.

We define a dummy variable

$$(15) \quad Y^D_{i,t,j} = \begin{cases} 1, \text{ iff } Y_{i,t,j} \geq \tilde{Y}_j \\ 0, \text{ iff } Y_{i,t,j} < \tilde{Y}_j \end{cases}, \qquad i=1,\ldots,N, \; t=0,\ldots,T, \; j=1,2 .$$

In our econometric specification, $Y_{i,t,j}$ depends on the realization of both product and process innovations in the previous period, $Y^D_{i,t-1,l}$, l=1,2, on a vector $x_{i,t,j}$ of measured variables assumed to be exogenous, and on the unobserved random variable $v_{i,t,j}$:

$$(16) \quad Y_{i,t,j} = \sum_{l=1}^{2} \lambda_{j,l} Y^D_{i,t-1,l} + \beta_j' x_{i,t,j} + v_{i,t,j} .$$

We expect that, due to unobserved heterogeneity, for a given firm the random term $v_{i,t,j}$ is serially correlated. If we do not control for this autocorrelation in the error term, the regression parameters are inconsistently estimated and significant λ-parameters in (16) may be the result of information on lagged values of $v_{i,t,j}$ contained in the past occurence variables $Y_{i,t-1,j}$. In order to get a tractable model, we decompose $v_{i,t,j}$ as the sum of a firm specific effect, ε_i, assumed to be constant over time, and a shock variable, $u_{i,t,j}$, which may vary over firms, time and innovation type.

(17) $v_{i,t,j} = \varrho_j \varepsilon_i + u_{i,t,j}$.

Since we normalize the variance of ε_i to unit, ϱ_j measures the strength of the firm specific effect for innovative activity j. We assume that ε_i and $u_{i,t,j}$ follow a multivariate normal distribution with

(18) $E(\varepsilon_i) = E(u_{i,t,j}) = 0$ for all i, t, j,
$\mathrm{var}(\varepsilon_i) = 1$ for all i,
$\mathrm{var}(u_{i,t,j}) = \sigma_j^2$ for all i, t, j,
$\mathrm{cov}(\varepsilon_i, \varepsilon_j) = 0$ if $i \neq j$
$\mathrm{cov}(\varepsilon_i, u_{i,t,j}) = 0$ for all i, t, j
$\mathrm{cov}(u_{i,t,j}, u_{i',t',j'}) = 0$ if $i \neq i'$ or $t \neq t'$ or $j \neq j'$.

This specification of the one factor random effects model implies that for a given firm i the error terms $v_{i,t,j}$ are equi-correlated, i.e. $\mathrm{cov}(v_{i,t,j}, v_{i,t',j}) = \varrho_j^2$ and $\mathrm{cov}(v_{i,t,1}, v_{i,t,2}) = \varrho_1\varrho_2$. A further implication is that, given ε_i, the error terms $v_{i,t,j}$ are conditionally independent.

Given $x_{i,t,j}$, $Y^D_{i,t-1,l}$ and ε_i, the conditional probability that $Y^D_{i,t,j} = 1$ is

$$(19) \quad \Pr(Y^D_{i,t,j} = 1 \mid Y^D_{i,t-1,l}, x_{i,t,j}, \varepsilon_i) = \Pr(Y_{i,t,j} \geq \tilde{Y}_j) =$$

$$\Pr(u_{i,t,j}/\sigma_j \leq \sum_{l=1}^{2} \tilde{\lambda}_{j,l} Y^D_{i,t-1,l} + \tilde{\beta}_j' x_{i,t,j} + \tilde{\varrho}_j \varepsilon_i)$$

with $\tilde{\beta}_j = \beta_j/\sigma_j$, $\tilde{\lambda}_{j,l} = \lambda_{j,l}/\sigma_j$ and $\tilde{\varrho}_j = \varrho_j/\sigma_j$. The threshold variable $\tilde{Y}_j$ is absorbed in the constant term included in the vector x. In short-hand notation we can write

$$(20) \quad \Pr(Y^D_{i,t,j} = 1 \mid Y^D_{i,t-1,l}, x_{i,t,j}, \varepsilon_i) = \Phi(z_{i,t,j}(\varepsilon_i))$$

with Φ the cumulative normal distribution and $z_{i,t,j} \equiv \sum_{l=1}^{2} \tilde{\lambda}_{j,l} Y^D_{i,t-1,l} + \tilde{\beta}_j' x_{i,t,j} + \tilde{\varrho}_j \varepsilon_i$. Since Φ is symmetric about zero, the conditional probability that $Y^D_{i,t,j}=0$ is $1-\Phi(z_{i,t,j}(\varepsilon_i))=\Phi(-z_{i,t,j}(\varepsilon_i))$. For a given value of ε_i and the initial values $Y^D_{i,0,1}$ and $Y^D_{i,0,2}$, the conditional probability of an observed sequence of tupels $(Y^D_{i,t,1}, Y^D_{i,t,2})$, t=1,...,T, is given by the product of the single probabilities $\Pr(Y^D_{i,t,j})$,

$$(21)\quad \Pr(Y^D_{i,1,1}, Y^D_{i,1,2}, Y^D_{i,2,1}, Y^D_{i,2,2}, \dots, Y^D_{i,T,1}, Y^D_{i,T,2})$$

$$\equiv L^*_i(\varepsilon_i) = \prod_{t=1}^{T} \Phi\,(\, z_{i,t,1}(\varepsilon_i)\,(2Y^D_{i,t,1}-1))\;\Phi(\, z_{i,t,2}(\varepsilon_i)\,(2Y^D_{i,t,2}-1)\,)\,.$$

To get the unconditional probability $\tilde{L}_i$, we multiply this product by the density function of ε_i and integrate with respect to ε_i

$$(22)\quad \tilde{L}_i = \int_{-\infty}^{\infty} L^*_i(\varepsilon_i)\,\varphi(\varepsilon_i)\,d\varepsilon_i$$

where $\varphi(\varepsilon_i)$ denotes the normal density function.

One problem not discussed so far concerns the specification of the initial conditions. The stochastic process $\{Y^D_{i,t,j}\}$ has started a long time ago, but typically we have observations only for a few time periods $t = 0, 1, \dots, T$. Since the error term $v_{i,t,j}$ is serially correlated, the initial values $Y^D_{i,0,j}$ are not exogenous. We have to treat the initial values as part of the statistical model and follow a procedure suggested by Heckman (1981b). In this approach the unobserved variables $Y_{i,0,j}$ are approximated by a linear function of exogenous variables observed in period 0 and the firm specific effect ε_i

$$(23)\quad Y_{i,0,j} = \beta'_{0,j}\, x_{i,0,j} + \varrho_{0,j}\,\varepsilon_i + u_{i,0,j}$$

with $u_{i,0,j} \sim N(0,\sigma^2_{0,j})$. The conditional probability that $Y^D_{i,0,j}=k$, $k=0,1$, given ε_i, can be expressed as

$$(24)\quad \Pr(Y^D_{i,0,j}=k) = \Phi\,(\, z_{i,0,j}(\varepsilon_i)\,(2Y^D_{i,0,j}-1)\,)$$

with $z_{i,0,j}(\varepsilon_i) = \tilde{\beta}'_{0,j}\, x_{i,0,j} + \tilde{\varrho}_{0,j}\,\varepsilon_i$, $\tilde{\beta}_{0,j} = \beta_{0,j}/\sigma_{0,j}$, $\tilde{\varrho}_{0,j} = \varrho_{0,j}/\sigma_{0,j}$. The unconditional joint probability L_i for all observations $(Y^D_{i,0,1}, Y^D_{i,0,2}, Y^D_{i,1,1}, Y^D_{i,1,2}, \dots, Y^D_{i,T,1}, Y^D_{i,T,2})$ can be written as

$$(25)\quad L_i = \int_{-\infty}^{\infty} \prod_{t=0}^{T} \prod_{j=1}^{2} \Phi\,(\, z_{i,t,j}(\varepsilon_i)\,(2Y^D_{i,t,j}-1)\,)\;\varphi(\varepsilon_i)\,d\varepsilon_i\,.$$

L_i is the contribution of observation i to the likelihood function. The log-likelihood function for all observations $i=1,\dots,N$ is then given by

$$(26)\quad \ln L = \sum_{i=1}^{N} \ln L_i\,.$$

The computation of the likelihood function requires a numerical integration in (25) which is performed by using the Gauss-Legendre-procedure. If the model is correctly specified, the ML-estimator is consistent and asymptotically normal. The asymptotic variance-covariance matrix, which is needed for the calculation of the t-statistics, is estimated as

$$(27) \quad \hat{V}_{\Theta} = - \left[\sum_{i} (\partial^2 \ln L_i) / (\partial\theta \, \partial\theta') \right]^{-1}$$

where all parameters are collected in the vector θ and the numerically calculated second derivatives are evaluated at the estimated parameter values $\hat{\theta}$. All estimates were performed with GAUSS386.

4. The Data and Empirical Results

We estimate our model with panel data for 308 firms of the West German manufacturing sector. The panel data were collected by the Ifo Institute in Munich and are part of the Ifo Konjunkturtest (see Oppenländer, Poser 1989, p. 269). The data set includes realized product and process innnovations as dichotomous variables, the number of employees, and the industrial classification of each firm. The industrial classification can be found in Table A in the appendix. The period ranges from 1979 to 1986 and includes the German recession after the second oil price shock and the following prosperity. The industrial classification of the panel data enabled us to add variables at the two-digit industry level. Data for real and nominal value added, and average gross wages of employees are taken from the yearly disaggregated national income accounts of the Statistisches Bundesamt, Fachserie 18. The Herfindahl indices of market concentration are taken from the Statistisches Bundesamt, Fachserie 4, Reihe S 9.

From the Ifo Konjunkturtest, we use the following variables at the firm level:

Y_1: Product innovations realized (0: no; 1: yes)
Y_2: Process innovations realized (0: no; 1: yes)
S: Firm size, measured by the number of employees
Q: Expected change of demand for the product (-1: negative; 0: no change; 1: positive) .

We merged the following data at the two-digit industry level:
SH: Relative firm size, calculated as the ratio of the firm's number of employees (S) to total employment in the respective industry
H: Market concentration, measured by the Herfindahl index
W: Real labor costs per employee, including employer's social security contributions (the price index is defined as nominal value added divided by real value added).

Since 8 years are a rather short time period, we selected only those firms that reported the relevant variables in each year. Some summary statistics of the data are given in Table 1.

Table 1: Descriptive Statistics of the Data

Variable	Mean	Min	Max
Y_1^D	0.591	0	1
Y_2^D	0.550	0	1
S $(x10^{-3})$	0.651	0.004	38.533
SH $(x10^{2})$	0.190	0.001	10.738
H $(x10^{1})$	0.17	0.02	1.08
Q	0.23	-1	1
W $(x10^{-5}$DM)	0.366	0.224	0.524

The estimated coefficients and t-statistics are reported in Table 2. Column 1 contains the parameter estimates for the single equation model explaining the realization probability of product innovations, Column 2 the parameters for the same model explaining the realization probability of process innovations. Columns 3 and 4 present the results of the simultaneous estimation of both equations. It turns out that the estimated coefficients of the single equations and the simultaneous equations are very similar.

The upper part of the table shows the parameters of the equations we used to model the initial conditions. Since the equations for initializing the stochastic processes can not be interpreted as structural, it should not be surprising that some parameters are insignificant or even have the wrong signs. The only variables with significant coefficients are the expected change of demand, Q, and the latent firm specific effect, ε. Including dummies for the main industry groups did not change these results qualitatively. Unfortunately, we have no further pre-sample information to specify the initial conditions more successfully.

The lower part of Table 2 contains the results for the structural equations which are central for our interpretations. The first two columns show that there are highly significant positive impacts of past innovations on the probability of realizing an innovation of the same type. These effects are confirmed in the simultaneous equation approach. They indicate that there is strong state dependence in the innovation process. Hence, our empirical evidence lends support to the success breeds success hypothesis discussed above. However, it is worth noting, that there are no dynamic cross effects of past product innovations on current process innovations

Table 2: Estimates of the Parameters of the Random Probit Model *

	Single Equation Est.		Simultaneous Est.	
Variable	Product	Process	Product	Process
		Initial Conditions		
CON	0.17	-0.38	-0.03	-0.45
	(0.31)	(-0.70)	(-0.05)	(-0.82)
S	0.04	-0.03	0.03	-0.03
	(0.72)	(-0.57)	(0.55)	(-0.58)
SH	0.22	0.16	0.26	0.20
	(0.94)	(0.78)	(1.02)	(0.91)
H	0.98	0.53	0.86	0.61
	(0.79)	(0.44)	(0.68)	(0.48)
H2	-1.05	-0.01	-0.86	-0.12
	(-0.70)	(-0.01)	(-0.56)	(-0.08)
Q	0.58	0.42	0.53	0.37
	(4.24)	(3.24)	(3.93)	(2.86)
W	-1.11	0.68	-0.50	0.88
	(-0.68)	(0.43)	(-0.31)	(0.54)
ε	0.55	0.50	0.58	0.59
	(4.59)	(4.27)	(5.10)	(5.25)
		Structural Equations		
CON	-0.61	-1.09	-0.89	-1.36
	(-1.75)	(-3.33)	(-2.54)	(-4.17)
$Y^D_{1,-1}$	0.60	-	0.56	-0.01
	(6.86)		(6.42)	(-0.06)
$Y^D_{2,-1}$	-	0.44	0.02	0.42
		(5.43)	(0.21)	(5.21)
S	0.07	0.12	0.06	0.11
	(2.18)	(3.49)	(1.84)	(3.38)
SH	0.22	-0.07	0.29	-0.03
	(1.49)	(-0.82)	(1.99)	(-0.40)
H	1.76	1.66	1.66	1.63
	(2.32)	(2.33)	(2.13)	(2.26)
H2	-2.04	-1.78	-1.95	-1.83
	(-2.39)	(-2.20)	(-2.23)	(-2.26)
Q	0.30	0.21	0.24	0.19
	(5.09)	(3.80)	(4.18)	(3.47)
W	0.90	2.10	1.74	2.91
	(0.90)	(2.25)	(1.74)	(3.14)
ε	0.77	0.71	0.84	0.76
	(9.88)	(9.94)	(10.93)	(10.69)

* t-values in parentheses

and vice versa. The market structure variables influence innovative behavior as suggested by some Schumpeterian hypotheses (see e.g. the survey by Kamien, Schwartz 1982, ch. 3). Absolute firm size has a positive significant impact on innovations, whereas relative firm size seems to be relevant only for product innovations. The sign pattern of the Herfindahl coefficients reflects a significant inverted U-shaped relationship between innovative activity and market concentration. In all versions the probability of an innovation attains its maximum at Herfindahl values of about 0.04 which lie in the middle of the concentration indices in our sample. The highly significant coefficients of the expected change in demand indicates that firms optimistic about the future development of their market increase their activities devoted to product and process innovations. This result supports the demand pull hypothesis suggested by Schmookler (1966). The real wage rate serving as a proxy for future production costs seems to be a major determinant for process innovations, but of only minor importance for product innovations. Large values of real wages cause a cost push and induce substitution of labor input by technological knowledge. In all versions we have significant evidence for unobserved firm specific effects which operate simultaneously on both types of innovative activity. This implies that simple probit models that ignore unobserved heterogeneity produce inconsistently estimated coefficients. However, the dynamic random effects probit model seems to be an appropriate method for analyzing both heterogeneity and structural dynamics of firms' innovative activity.

5. Summary and Conclusion

In this paper we developed a dynamic random effects probit model based on a theoretical optimization model of firms' innovative behavior. We investigated the dynamics of product and process innovations. The most import contribution of our model is that we account for unobserved firm specific characteristics and the possibility that innovative success leads to further success in the following periods. By using a panel data set of 308 firms of the West German manufacturing sector, we showed that for both types of innovation lagged realized innovations of the same type, but not lagged realized innovations of the other type, have indeed a strong positive influence on the probability of further innovations. Although we controlled for unobserved heterogeneity of firms, we supported in addition some Schumpeterian hypotheses. We derived positive effects of absolute and relative firm size as well as an inverted U-shaped relationship between market concentration and innovative activity. Finally, we found empirical evidence for the demand pull and cost push hypotheses. The results presented in this study are encouraging for further research. We hope that proceeding along the suggested lines will prove the slogan: Success Breeds Success.

Table A: Industrial Classification and Number of Firms (N)

No	Industry	N
25	Stones and clay	4
30	Drawing plants etc.	5
31	Structural metal products	4
32	Mechanical engineering	62
33	Road vehicles	9
34	Ship building	2
36	Electrical engineering	28
37	Precision and optical instruments	15
38	Finished metal goods	20
39	Musical instruments, toys etc.	4
40	Chemical products	6
51	Ceramic goods	9
52	Glass	9
53	Wood working	4
54	Wood products	12
55	Paper manufacturing	5
56	Paper processing	9
57	Printing and duplicating	13
58	Plastic Products	29
61/62	Leather	9
63	Textiles	22
64	Clothing	6
68	Food and beverages	22
Total		308

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