Technical change in Developing Countries: A dynamic model of adoption, learning and industry evolution

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ABSTRACT

This paper develops and analyses a dynamic model, which combines both the adoption and the industry evolution theories. We model the decision of adoption, learning entry and exit of firms. These decisions depend on the interaction of technology characteristics ((effectiveness, machinery and information costs…) and other economic indicators (firm's size, technology capability, competition concentration, returns of scale,…). We use the model's theoretical results to analyze simultaneously the effects on the structure and the average efficiency of the industry and to develop a framework for understanding the effect of competitive policy reform and public policy action necessary to enhance adoption and average productivity. The model we suggest also analyses effects on industry evolution and social welfare.

Keywords*: A*doption, learning, efficiency, entry , exit, industrial dynamics, evolution, developing countries.
JEL- Classifications: L1, L11, L22, L25, O3, O31, and O33.

INTRODUCTION

Much of the theoretical modeling in new growth theory has been in the context of the industrialized countries and focused primarily on R&D expenditures and investments in human physical capital as determinants of technological evolution. In developing economies, in contrast, where technologies are imported from industrialized countries, the R&D is oriented to the technological efforts that can enable firms to reach "best practice" levels of adopted technologies and that determine the intensity with which industrial technologies already used by firms are changed by continuing adaptation and incremental improvement. .

Experience in developing countries indicates that these technical adoption and learning process are far more complex and demanding. The use of imported technologies, at or near "the best practice" level of technical efficiency for which it was designed, requires firms to seek new information, skills, material inputs, investment resources and management organizations .The adoption of innovations is not an automatic or passive process, in these countries, and the technological success of this adoption is uncertain.

Differences in firm-specific initial endowments of technological capabilities and entrepreneurial ability facilitate technological success by particular firms. Over time these firms learn more effectively than other enterprises and they may stay ahead or widen the technology gap. As a consequence, the technological adoption and learning processes, themselves, inevitably create technology gaps and affect the structure and the heterogeneity of the industry.

Developing countries appear to suffer from a significant technology gap between national and foreign firms. Part of this gap appears to be due to a great deal of heterogeneity in efficiency across firms in developing countries. The main policies suggested are the intensification of the competition by exposing national firms to world competition and eliminating artificial restraints to competition such that barriers to entry; and the reallocation of resources away from less efficient firms to more efficient firms and sectors to improve aggregate productivity.

A key set of policy issues revolves around the relationship of inter-firm productivity differentials to firm size and employment creation. Researchers and policy makers have often associated the capacity to create employment with firm size. In developing economies, for example, micro-enterprises and small firms have often been viewed as important elements in the objectives of employment generation and poverty alleviation. To evaluate these policies and to find those which can have the greatest impact on increasing firm productivity and social welfare, we must focus simultaneously on both adoption and industrial evolution theories.

The purpose of this paper is to generalize previous studies by combining, both theories of adoption (Feder [1980], Fudenberg and Tirole (1985), Feder, Just and Silberman [1984], Jensen (1992), Hoppe (2000) and others), and industry evolution (Jovanovic (1982), Lippman and Rumelt (1982), Gort and Klepper (1982), Dixit and Shapiro (1986), Jovanovic and Lach (1989), Ericson and Pakes (1989, 1990), Lambson (1991,1992), Hopenhayen (1992) D.B.Audretsch et Talat Mahmood (1994) and others). We present in the first section, a dynamic model of adoption and learning in which we formalize explicitly the firms' entry and exit decisions, in a market for a differentiated product with monopolistic competition. In the second section we analyze theoretical results relative to firms' adoption, efficiency and industry concentration and average productivity. The effects on industry evolution and social welfare are discussed in other paper.

THE MODEL

Demand side:

I formalize a monopolistic competition model, using a derivation of Dixit and Stiglitz (1977) and Spence (1976). Each firm produces a unique brand of the same generic product. Hence, at any given time *t,* the number of firms operating, *n* (*t*), equals the number of varieties available to consumers.

The preference ordering of identical consumers is described by the inter-temporal utility function:

$$U = \int_0^\infty e^{-rt} \left(x_0(t) + \log C(t) \right) dt \tag{1}$$

Where $x_0(t)$ is the consumption of the numeraire in time *t,* and $C(t)$ is the consumption index of the Dixit-Stiglitz type

$$C(t) = \left(\int_0^{n(t)} y_j(t)\alpha \quad dj \right)^{1/\alpha} \qquad where \quad 0 < \alpha < 1 \tag{2}$$

Where $y_j(t)$ is the amount of variety *j* of the differentiated product demanded by a consumer at time *t*. The aggregate demand function $Y_j(t)$ for variety *j* at time *t* is:

$$Y_j(t) = \frac{p_j(t)^{1/(\alpha-1)}}{\int_0^{n(t)} p_i(t)^{\alpha/(\alpha-1)} \, di} E \tag{3}$$

Where *E* is equal to the total instantaneous expenditure on the differentiated product and $p_j(j)$ is the price of variety *j* at time *t.* The demand function (3) is isoelastic with the elasticity of demand $\sigma = 1/(1-\alpha)$

Cost side:

The technology used by the firm is described by the cost function: $C_j^x(t) = \hat{c}_j^x(t)\, y_j(t) + F$. Where F is the fixed cost and $\hat{c}_j^x(t)$ is the marginal cost. Across firms $c\hat{x}$'s are random and take three possible values $\hat{c}_j^o(t)$, $\hat{c}_j^l(t)$ and $\hat{c}^h$ with $\hat{c}^h < \hat{c}_j^l(t) < \hat{c}_j^o(t)$. Firms experiencing $\hat{c}_j^o(t)$ are the lowest-efficiency (*o*-) firms, which still use the old technology. Those experiencing $\hat{c}_j^l(t)$, have adopted the new technology but they are still engaged in learning, adaptation and search efforts in order to succeed adoption and to use the new technology efficiently. Finally the high-efficiency (*h*-) firms which have achieved their successful adoption and learning process, use the new technology at the "best practice" level of technical efficiency for which it was designed ($\hat{c}^h$). We assume that $c_j^l(t)$ follows a conditional distribution $F\ (c_j^l(t+1)\ /\ c_j^l(t))$ which is the probability of having a productivity equals to $c_j^l(t+1)$, in period *t*+1 given $c_j^l(t)$ in period *t. F* is continuous in $c_j^l(t)$ and $c_j^l(t+1)$, strictly increasing in $c_j^l(t)$ and is the same for all firms. We define the probability of adoption success of firm *j*, in period *t,* by $F\ (c^h\ /\ c_j^l(t))$, which is the probability to use the new technology at the "best practice" level of technical efficiency ($\hat{c}^h$) in period *t*+1 given $c_j^l(t)$ in period *t.*

Hypothesis 1: We assume that $c_j^x(t) = \hat{c}_j^x(t)^{-\theta}$ where $c_j^x(t)$ can be considered as an indicator of the x-firm productivity, in period *t*. Thus $c_j^o(t) = \hat{c}_j^o(t)^{-\theta}$, $c_j^l(t) = \hat{c}_j^l(t)^{-\theta}$ and $c^h = \hat{c}^{h^{-\theta}}$.

Market equilibrium:

It is assumed that firms discover their type at the beginning of each period. A firm *j* of type *x* (*x* = *o, l, h*) which stays maximizes profits $\pi_j^x(t) = p_j(t)\, y_j(t) - \hat{c}_j^x(t)\, y_j(t) - F_t$, subject to the demand curve it faces given in (3). The optimal pricing rules for firm *j* of type *x* is: $p_j(t) = \hat{c}_j^x(t)\left(\frac{\theta}{1+\theta}\right)$ where $\left(\frac{\theta}{1+\theta}\right)$ is the mark-up over the marginal cost and $\theta = \frac{\alpha}{1-\alpha}$.

Using this pricing rule, the profit expression of the firm *j* of type *x* is: $\pi_j^x(t) = \frac{c_j^x(t)\, E}{(\theta+1)cm_t\;\, n(t)} - F_t$

$cm_t = \frac{1}{n(t)}\int_0^{n(t)} c_j^x(t)\;\; dj$. Where cm_t is the industry average productivity during this period. Thus cm_t^l and cm_t^o , are respectively the average productivities of (*l*-) and *o*-firms in this period.

$$cm_t^l = \frac{1}{n^l(t)}\int_{n^h(t)}^{n^h(t)+n^l(t)} c_j^l(t)\;\; dj \quad \text{and} \quad cm_t^o = \frac{1}{n^o(t)}\int_{n^h(t)+n^l(t)}^{n(t)} c_j^o(j)\;\; dj \qquad (4)$$

Hypothesis 2: We assume that $c_j^x(t) = A(j,t)\, cm_t$ with $A(j,t) \geq 0$ for all *j*, is a continuous and monotonously decreasing function of the firm index *j*. That is, firms are ranked in terms of this parameter in such a way that more efficient firms have a lower index number. We assume a specific functional form for $A(j,t)$, namely: $A(j,t) = 1 + \varepsilon(t)\left(\frac{1}{2} - \frac{j}{n(t)}\right) \qquad 0 < \varepsilon(t) < 2 \qquad (5)$

Where $\varepsilon(t)$ is an endogenous parameter measuring the industry concentration (or firms' heterogeneity). We can see that higher values of this parameter imply a greater inter-firm variance in productivity and size. As $\varepsilon(t)$ converges to zero the industry becomes homogenous and $A\;(j,\; t)$ converges to 1.

Finally we can see that in the expression $c_j^x(t) = A(j,t)\, cm_t$ the type of the firm does not matter. To make difference between (*l*-) and *o*-firms (which is necessary to avoid undetermined form and to solve the model) we assume that $c_j^l(t) = l.A(j,t)\, cm_t\,(t)$ and $c_j^o(t) = o.A(j,t)\, cm_t\,(t)$. Where *l* and *o* are two different positive values very close to 1(logically $l > o$). This hypothesis does not affect results since *l* and *o* are instrumental variables which will disappear by simplification).
The expressions of the (*l*-) and *o*-firms profits can be written as follow:

$$\pi_j^l(t) = \frac{l.\; A(j,t)\; cm_t \quad E}{(\theta+1)\,(c^h\, n^h(t) + cm_t^l\, n^l(t) + cm_t^o\, n^o(t)} - F_t$$

$$\pi_j^o(t) = \frac{o.\; A(j,t)\; cm_t \quad E}{(\theta+1)\,(c^h\, n^h(t) + cm_t^l\, n^l(t) + cm_t^o\, n^o(t)} - F_t \qquad (6)$$

The value functions

Potential entrants and incumbent firms maximize expected discounted profits. The problem of an incumbent firm using the old technology is defined recursively by:

$$v_j^o(t,\; c_j^o(t)) = \pi_j^o(t) + \max\left\{ S^o\;;\beta\left[\, h_j(t).v_j^l(t{+}1, c_j^l(t{+}1)) + (1 - h_j(t)).v_j^o(t{+}1, c_j^o(t{+}1))\,\right]\right\} \quad (7)$$

Where $v_j^o(t, c_j^o(t))$ gives the value of a firm *j* of type *o*, at period *t*. $S^o \geq 0$ is the *o*-firm's opportunity cost of being in the industry. $h_j(t)$ is the hazard rate or the new technology adoption probability, of firm *j*, in period *t*. The value of firm *j* of type *l* in period *t*, is :

$$v_j^l(t, c_j^l(t)) = \pi_j^l(t) + \max\left\{ S^i \; ; \beta \int_{ch}^{c_j^l(t)} v_j^l(t{+}1, c_j^l(t{+}1)) \; F\;(c_j^l(t{+}1) \,/\, c_j^l(t)) \quad dc_j^l(t{+}1) \right\} \tag{8}$$

Where S^i is the opportunity cost of being in the industry of *l*- and *h*- firms. S^i is assumed the same for an *h*-firm or an *l*-firm. $F\,(c_j^l\,(t{+}1)\,/\,c_j^l\,(t))$ is defined above. This *l*-firms become of type *h,* in period *t*+1 if they succeed their adoption and learning process in period *t*, i.e. $F\,(ch\,/c_j^l\,(t)\,) = 1$. The *h*-firms' value is:

$$v_j^h\,(t, c^h\,) = \pi_j^h\,(t) + \max\left\{ S^i \; ; \; \beta \; v^h\,(t{+}1, c^h\,) \right\} \tag{9}$$

Industry dynamics:

The composition of firms evolves in accordance with average probabilities of adoption (*o*-firms), of technical success (*l*-firms) and of entry and exit (*o*, *l* and *h*-firms). The number of *h*-firms evolves according to:

$$n^h(t{+}1) = n^h(t) + \rho\,(t)\,n^l\,(t) - ns^h\,(t) \tag{10}$$

Where $\rho(t)$ is the average probability of success : $\rho(t) = \dfrac{1}{n^l\,(t)} \displaystyle\int_{n^h\,(t)+n^l\,(t)}^{n(t)} F(c^h\,/c_j^l(t)) \; dj$ (11)

Thus $\rho(t)\,n^l\,(t)$ is the number of *l*-firms, which have achieved, with success, their adoption and learning process and become high-efficiency firms. $h(t)$ is the average probability of adoption of *o*-firms, in period *t*, then: $h(t) = \dfrac{1}{n^o\,(t)} \displaystyle\int_{n^h\,(t)+n^l\,(t)}^{n(t)} h_j(t) \quad dj$ (12)

Let $n^a\,(t)$ the number of *o*-firms which adopt the new technology in period *t*, then $n^a\,(t) = h(t)\,.n^o\,(t)$ (13)

The number of *o*-firms, $no(t)$, evolves according to: $n^o(t{+}1) = n^o\,(t) - n^a\,(t) + ne^o\,(t) - ns^o\,(t)$ (14)

$ns^o(t)$ is the number of exit among non innovating firms of type *o*, at the end of period *t* (or at the beginning of period *t*+1). $ne^o\,(t)$ is the number of firms which enter the industry at the end of period *t,* using the old technology.

Let $ne^l\,(t)$ the number of innovating entrants of type *l* and $ns^l\,(t)$ the number of exits among *l*-firms. The total number of *l*-firms in period *t*+1 is: $n^l\,(t{+}1) = (1 - \rho(t))\,n^l\,(t) + n^a(t) + ne^l\,(t) - ns^l\,(t)$ (15)

Finally, the total number of active firms in period *t,* $n(t)$, is: $n(t) = n^h\,(t) + n^l\,(t) + n^o\,(t)$ (16)

This total number evolves in according to: $n(t{+}1) = n(t) + ne(t) - ns(t)$ (17)

Where $ns(t)$ is the total number of exits at the end of period *t*: $ns(t) = ns^h\,(t) + ns^l\,(t) + ns^o\,(t)$ (18)

$ne(t)$ is the total number of entry at the end of period *t*: $ne(t) = ne^l\,(t) + ne^o\,(t)$ (19)

The adoption decision:

A firm j^a maximizes the discounted value of total profits by choosing the adoption date *T*. Denoting the total profit function as $\Pi_{ja}(T)$ the optimization problem of this firm is as follow:

$$\Pi_{ja}(T) = \int_0^T e^{-rt}\,\pi_{ja}^o\,(t)\;dt + \int_T^{T+\tau} e^{-rt}\,\pi_{ja}^l\,(t)\,dt + \int_{T+\tau}^{+\infty} e^{-rt}\,\pi^h\,(t)\,dt - e^{-rT}\,Xa(T) \tag{20}$$

This profit function can de differentiated with respect to *T*. One gets the first-order condition of the profit-maximization problem:

$$\frac{d\Pi_{ja}(T)}{dT} = e^{-rT}\left(\pi^{o}_{ja}(T)-\pi^{l}_{ja}(T)\right)+e^{-r(T+\tau)}\left(\pi^{l}_{ja}(T+\tau)-\pi^{h}_{ja}(T+\tau)\right)-e^{-rT}\left(xa_T - r\,Xa(T)\right)=0 \quad (21)$$

Where $Xa(T)$ is the adoption cost of the new technology in period *T*. xa_T is the derivative of $Xa(T)$ with respect to *T*. $T+\tau$ is the date of technical success of firm j^a, such that $F(c^h / c^l_{ja}(T+\tau-1)) = 1$. At this date technical efficiency $c^l_{ja}(T+\tau)$ equals c^h, thus: $\pi^h(T+\tau) = \pi^l_{ja}(T+\tau)$. Eqs (21) writes:

$$e^{-rT}\left[\pi^{o}_{ja}(T) - \pi^{l}_{ja}(T)\right] = e^{-rT}\left(xa_T - r\,Xa(T)\right) \quad (22)$$

If we replace in (22), $\pi^o_{ja}(T)$ and $\pi^l_{ja}(T)$ by their expressions (Eqs 6), we obtain (23).

$$\frac{A(j^a, T)(o-l)\;E}{(\theta+1)(c^h n^h(T) + cm^l_T n^l(T) + cm^o_T n^o(T)} = xa_T - r\,Xa(T) \quad (23)$$

We can deduce from (23) that at any given date *t*, there is a rank j^a such that condition (24) holds.

$$(\theta+1)(c^h n^h(t) + cm^l_t n^l(t) + cm^o_t n^o(t) = \frac{A(j^a, t)(o-l)\;E}{(xa_t - r\,Xa(t))} \quad (24)$$

We assume that j^a is the critical rang above which firm can not adopt the new technology, in period *t*. Hence all *o*-firms which are larger and more efficient than firm j^a (i.e. which have lower rank than j^a), adopt in this period. The total number of firms which adopt in period *t* is given by Eqs: $n^a(t) = j^a - (n^h(t)+n^l(t))$ (25)

One gets the expression of j^a given by : $j^a = n^a(t) + n^h(t) + n^l(t)$ (26)

The *o*-firms exit decision:

The exit decision is made prior to observing next period's efficiency level and will involve a reservation rule:

$$h_{\hat{j}}(t)\; v^l_{\hat{j}}(t+1, c^l_{\hat{j}}(t+1)) + (1 - h_{\hat{j}}(t))\; v^o_{\hat{j}}(t+1, c^l_{\hat{j}}(t+1)) = S^o \quad (27)$$

A firm using the old technology will exit the industry the first time its rank gets above this reservation value $\hat{j}$, i.e. the first time $j>\hat{j}$. Thus the number of *o*-firms exits, $ns^o(t)$, is given by: $ns^o(t) = n(t)-\hat{j}$ (28)

Finally there exists, for any given *t*, a critical rank $\hat{j}$ such that (29) is respected. ((29) is obtained by combining (6), (7) and (27)) : $(\theta+1)(c^h n^h(t) + cm^l_t n^l(t) + cm^o_t n^o(t)) = \dfrac{o.A(\hat{j}, t)\; cm_t \quad E}{F_t + v^o_{\hat{j}}(t, c^o_{\hat{j}}(t)) - \beta S^o}$ (29)

The *l* and *h*-firms exit decisions:

The exit decision is made by *h*- and *l*-firms prior to observing next period's efficiency level $c^l_j(t)$ (or c^h if technical success) and will involve a reservation rule:

$$\int_{ch}^{c^l_{j*}(t+1)} v^l_{j*}(t+1, c^l_{j*}(t+1))\, F\left(c^l_{j*}(t+1) / c^l_{j*}(t)\right)\, dc^l_{j*}(t+1) = S^i \quad (30)$$

A firm using the new technology will exit the industry the first time its rank gets above this reservation value j^*, i.e. the first time $j>j^*$. Thus the number of exits of *l*- and *h*-firms, $ns^i(t)$, is given by:

$$ns^i(t) = n^h(t) + n^l(t) - j^* \quad (31)$$

Finally there exists, for any given t, a critical rank j^* such that (32) holds. (Eqs(32) is obtained by combining (6),(8) and (30)) :

$$(\theta+1)(c^h n^h(t) + cm_t^l n^l(t) + cm_t^o n^o(t)) = \frac{l.A(j^*,t)\ cm_t \quad E}{F_t + v_{j*}^l(t, c_{j*}^l(t)) - \beta S^i} \tag{32}$$

By combining (24) and (29) we obtain (33):

$$\hat{j} = U^o(t)\, j^a - \xi(t)\,(U^o(t)-1)\, n(t) \tag{33}$$

Where, $U^o(t) = \dfrac{(F_t + v_{\hat{j}}^o(t, c_{\hat{j}}^o(t)) - \beta S^o)\,(o-l)}{o.(xa_t - rXa(t))}$, and $\xi(t) = \dfrac{2+\varepsilon(t)}{2.\varepsilon(t)}$

The number of exit of o-firms (Eqs 34) is obtained by replacing (33) and (26) in (28):

$$ns^o(t) = \left[1+\xi(t)(U^o(t)-1)\right] n(t) - U^o(t)\left[n^a(t) + n^h(t) + n^l(t)\right] \tag{34}$$

Substituting this in (34), the number of o-firms operating in the industry in period t+1 can be expressed as:

$$n^o(t+1) = (n^h(t)+n^l(t))\left[(Uo(t)-1)(1-\xi(t)) + e^o(t)\right] + n^o(t)\left[(Uo(t)-1)(h(t)-\xi(t)) + e^o(t)\right] \tag{35}$$

Eqs (36) is obtained by combining (24) and (32): $j^* = U^i(t)\, j^a - \xi(t)\,(U^i(t)-1)\, n(t)$ (36)

Where $U^i(t) = \dfrac{\left[F_t + v_{j*}^l(t, c_{j*}^l(t)) - \beta\ S^i\right](o-l)}{l.\ (xa_t - r\,Xa(t))}$, and $\xi(t) = \dfrac{2+\varepsilon(t)}{2.\varepsilon(t)}$

If we substitute (36) and (26) in (31), the number of innovating firms exit becomes:

$$ns^i(t) = (n^h(t)+n^l(t))(1-U^i(t)) - U^i(t)\, n^a(t) + \xi(t)(U^i(t)-1)\, n(t) \tag{37}$$

The total number of l-firms becomes by replacing (37) in (15):

$$n^l(t+1) = \left[(U^i(t)-1)(1-\xi(t)) + e^l(t)\right] n^h(t) + \left[U^i(t)(1-\xi(t)) - \rho(t) + e^l(t) + \xi(t)\right] n^l(t)$$
$$+ \left[U^i(t)(h(t)-\xi(t)) + h(t) + e^l(t) + \xi(t)\right] n^o(t) \tag{38}$$

Innovative firms' entry decisions:

An entrant j^{el}, using the new technology, maximizes the discounted value of total profits by choosing the entry date T_{el}. Denoting the profit function as $\Pi_{j^{el}}(T_{el})$ the optimization problem of this entrant is as follow:

$$\Pi_{j^{el}}(T_{el}) = \int_{T_{el}}^{T_{el}+\tau} e^{-rt}\,\pi_{j^{el}}^l(t)\,dt + \int_{T_{el}+\tau}^{+\infty} e^{-rt}\,\pi^h(t)\,dt - e^{-rT_{el}}\,Xel(T_{el}) \tag{39}$$

The model's results:

Endogenous variables are solved in the Appendix 1. The numerical simulations of their expression show that industry concentration affects the diffusion of new technology among firms. It has a positive effect on the average probability of adoption. (Which is consistent with the schumpeterian assumption, according to which monopolistic profits are required to finance research and learning expenditures); and becomes inhibiting when it reaches a high critical level. We can thus deduce that the significant inter-firm variation in technical efficiency in developing countries which is the source of average inefficiencies of their industries prevent the adoption of new technologies and thus the productivity improvement in this countries.

We found that an improvement of the productivity of less efficient entering firms towards that of domestic best practice by supporting their learning and research processes reduces the industry heterogeneity. Economies of scale (high fixed costs) rise industry concentration, which increases in the adoption, learning, and entry costs.

We have shown that competitive policy reform has a strictly positive effect on the average probability of adoption and lead to some firms moving toward best practice while overall inter-firm variance in productivity increases. Together with policy reform, industry-specific training and technical assistance programs might help to overcome this problem. Finally, we find that the innovation effectiveness increases the probability of adoption and decreases the average probability of technological success of innovating firms.

LIMITATION OF THE STUDY AND FUTURE STUDIES

The framework developed here does not formalize explicitly technological externalities inherent to learning process but seems to be sufficiently flexible and simple to include this effect. In this article we have presented only results concerning adoption learning and efficiency. Results on the dynamics of entry, exit and industry evolution are discussed in another paper.

APPENDIX

Appendix 1

From Eqs(24) we can deduce: $(c^h n^h(t+1) + cm^l_{t+1} n^l(t+1) + cm^o_{t+1} n^o(t+1)) = \Omega^a(t)(c^h n^h(t) + cm^l_t n^l(t) + cm^o_t n^o(t))$

Where $\Omega^a(t) = \dfrac{k^a(j^a,t)\ (xa_t - r\,Xa(t))\,cm_{t+1}}{(xa_{t+1} - r\,X\,a(t+1))\,cm_t}$ And $k^a(j^a,t) = \dfrac{A(j^a,t+1)}{A(j^a,t)}$. $k^a(j^a,t)$ is a positive endogenous parameter. In the left side of (39) we replace $n^h(t+1)$, $n^l(t+1)$ and $n^o(t+1)$ by their expressions given, respectively, by (10) (38) and (35). We obtain (40).

$$n^h(t)\left\{c^h + cm^l_{t+1}\left[(U^i(t)-1)(1-\xi(t)) + e^l(t)\right] + cm^o_{t+1}\left[(U^o(t)-1)(1-\xi(t)) + e^o(t)\right]\right\}$$
$$+n^l(t)\left\{\rho(t)c^h + cm^l_{t+1}\left[U^i(t)(1-\xi(t)) - \rho(t) + e^l(t) + \xi(t)\right] + cm^o_{t+1}\left[(U^i(t)-1)(1-\xi(t)) + e^o(t)\right]\right\}$$
$$+n^o(t)\left\{cm^l_{t+1}\left[U^i(t)(h(t)-\xi(t)) + h(t) + e^l(t) + \xi(t)\right] + cm^o_{t+1}((U^o(t)-1)(h(t)-\xi(t)) + e^o(t))\right\}$$
$$= \Omega^a(t)\left[c^h n^h(t) + cm^l_t n^l(t) + cm^o_t n^o(t)\right]$$ this holds for any positive $n^h(t), n^l(t)$ and $n^o(t)$ if:

$$\begin{cases} c^h + cm^l_{t+1}\left[(U^i(t)-1)(1-\xi(t)) + e^l(t)\right] + cm^o_{t+1}\left[(U^o(t)-1)(1-\xi(t)) + e^o(t)\right] = \Omega^a(t)c^h & (1) \\ \rho(t)c^h + cm^l_{t+1}\left[U^i(t)(1-\xi(t)) - \rho(t) + e^l(t) + \xi(t)\right] + cm^o_{t+1}\left[(U^o(t)-1)(1-\xi(t)) + e^o(t)\right] = \Omega^a(t)cm^l_t & (2) \\ cm^l_{t+1}\left[U^i(t)(h(t)-\xi(t)) + h(t) + e^l(t) + \xi(t)\right] + cm^o_{t+1}\left[(U^o(t)-1)(h(t)-\xi(t)) + e^o(t)\right] = \Omega^a(t)cm^o_t & (3) \end{cases}$$

(1)-(2) implies $(1-\rho(t))(c^h - cm^l_{t+1}) = \Omega^a(t)((c^h - cm^l_t)$ and $\Omega^a(t) = \dfrac{(1-\rho(t))(c^h - cm^l_{t+1})}{(c^h - cm^l_t)}$

so $k^a(j^a,t) = \dfrac{(1-\rho(t))(c^h - cm^l_{t+1})\ (c^o(t) - c^l(t))(xa_{t+1} - rXa(t+1))}{(c^h - cm^l_t)(c^o(t+1) - c^l(t+1))(xa_t - rXa(t))}$

Multiplying (2) by $(h(t)-\xi(t))$ and (3) by $(1-\xi(t))$ gives respectively (2') and (3'):

$$(h(t)-\xi(t))\,\rho(t)c^h + (h(t)-\xi(t))\,cm^l_{t+1}\left[U^i(t)(1-\xi(t)) + (e^l(t) - \rho(t) + \xi(t))\right]$$
$$+(h(t)-\xi(t))cm^o_{t+1}\left[(U^o(t)-1)(1-\xi(t)) + e^o(t)\right] = (h(t)-\xi(t))\,\Omega^a(t)cm^l_t \qquad (2')$$

$$(1-\xi(t))\,cm^l_{t+1}\left[U^l(t)(h(t)-\xi(t) = + h(t) + e^l(t) + \xi(t)\right]$$
$$+ (1-\xi(t))\ cm^o_{t+1}((U^o(t)-1)(h(t)-\xi(t)) + e^o(t)) = (1-\xi(t))\Omega^a(t)cm^o_t \qquad (3')$$

(2') – (3') gives (4'): $(h(t)-\xi(t))\rho(t)c^h + cm^l_{t+1}\left[(h(t)-\xi(t))(el(t)-\rho(t)+\xi(t)) - (1-\xi(t))(el(t)+\xi(t)+h(t))\right]$

$$+e^o(t)cm^o_{t+1}(h(t)-1) = \frac{(1-\rho(t))(c^h - cm^l_{t+1})}{c^h - cm^l_t}\left[cm^l_t(h(t)-\xi(t)) - cm^o_t(1-\xi(t))\right]. \qquad (4')$$

From (4') we solve $h(t)$: $$h(t) = \frac{(c^h - cm^l_{t+1})\left[c^h \rho(t)\xi(t) + x(1-\rho(t))\, cm^o_t\right] + c^h \xi(t)(cm^l_{t+1} - cm^l_t) + D}{(c^h - cm^l_{t+1})\,\rho(t)c^h - c^h cm^l_t - cm^l_{t+1}(e c^h + 2\, x cm^l_t) + D}$$

Where $D = (c^h - cm^l_t)(e^l(t)\, cm^l_{t+1} + e^o(t)\, cm^o_{t+1})$ and $x = \xi(t) - 1$

There are 16 possible cases for entry and exit dynamic:
Case 1: is the general case presented in appendix 1: $e^l(t) \geq 0,\ e^o(t) \geq 0,\ ns^l(t) \geq 0,\ ns^o(t) \geq 0$, Case 2: Some l and o-firms enter but no exit: $(e^l(t) \geq 0,\ e^o(t) \geq 0,\ ns^l(t) = 0,\ ns^o(t) = 0$ Case 3: Some l and o-firms enter, only o-firms quit $e^l(t) \geq 0,\ e^o(t) \geq 0,\ ns^l(t) = 0,\ ns^o(t) \geq 0$, Case 4:Some l and o-firms enter bur only l-firms quit etc… From these particular cases we derive a system of eight equations with eight endogenous variables $(h(t), \rho(t), e^i(t), e^o(t), cm^o_t, cm^l_t, cm^o_{t+1}, cm^l_{t+1})$.

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FIGURES

Figure 1-a: The competition effect on the average probability of adoption

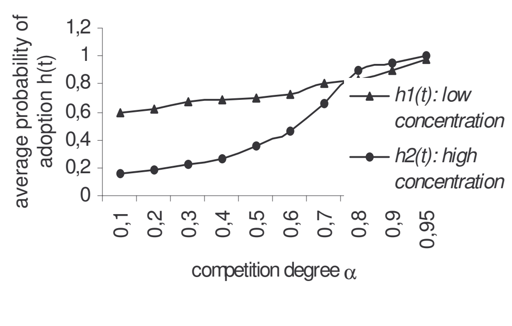

Figure 1-b: The concentration effect on the average probability of adoption

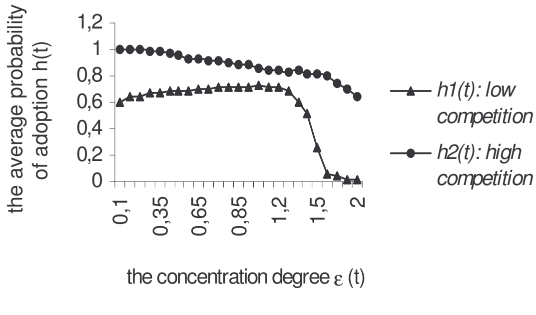

Figure 2-a: The concentration effect on the probability of technical success

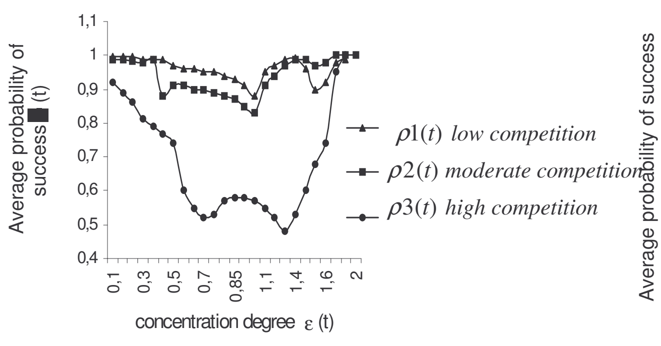

Figure 2-b: The effect of competition on the probability of technical success