Technological Change, Productive Efficiency and Industrial Dynamics: An Evolutionary Model

by

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Abstract

This paper analyses the impact of technological change and productive efficiency on the dynamics of industrial competition. Our theoretical model takes into account the innovation possibilities and the organisational structure of the firm. It considers three decision stages in which firms first have to solve for output and profits (and the market price), given the state of production techniques, decide about the technique to use in the next period, and finally decide whether continue, exit or enter in an industry. We evaluate the main predictions of the model by numerically simulating the impact of entry and exit barriers (and market demand growth) on industrial dynamics, namely on the evolution of the population of firms (entry and exit rates), the average productivity, and the productivity of continuing, entrants and exiting firms. This simulation exercise largely confirms the theoretical predictions of our study.

1. Introduction

This paper explores the impact of technological change and productive efficiency on industrial dynamics using a micro-simulation model. Our starting point is an emerging field in industrial economics which, spurred by the increasing availability of micro time series, has produced several stylised facts in many aspects of industrial dynamics, namely on entries, exits, growth rates, and changes in market shares of continuing firms (Caves, 1998, and Geroski, 1995, provide an extensive survey of this literature). In particular, these studies have shown that: (a) the turnover of firms improves firm productivity and efficiency, as new entrants are more productive and efficient than continuing firms; and (b) exiting firms are less efficient (e.g. Baldwin, 1992 and 1996; Geroski, 1991, 1995; and Lansbury and Mayes, 1996a and 1996b). A positive correlation has also been observed between the innovation rate and the entry rate (Geroski, 1994), while other studies have found that many firms are not efficient (Caves and Barton, 1990; Caves, 1992; Mayes, Harris and Lansbury, 1994, inter al.).

The seminal work of Nelson and Winter (1982), and the subsequent developments, provide a useful framework for the interpretation of industrial dynamics, particularly on three key issues: (a) the definition of firms (set of competences that the firm controls); (b) the differences between firms (routines and competences are specific and cannot be transferred); and (c) the evolution of firms (searching of routines and transformation of secondary routines into principal routines; Cohendet, Llerena and Marengo, 2000).

Our model, included in section 2, takes into account not only the definition of the innovation possibility frontier, but also the organisational structure of the firm, in particular, the Penrose theory of the growth of the firm, which stresses the importance of 'coherent administrative organisation' in the firm's productivity level and growth (Penrose, 1995: p. xii). Within this framework, we complement our analysis with a simulation exercise using the LSD (Laboratory for Simulation Development) software.

2. The model

Our model draws on two approaches: the evolutionary theory of the firm and Penrose's theory of the growth of the firm. In the first approach, routines and learning are identified as key concepts. Routines are the 'genes of the organisation', as they encompass the organisation's knowledge basis (the organisational memory). In this sense, routines guide organisation’s behaviour. (Nelson and Winter, 1982; Metcalfe, 1998) Accordingly, the evolutionary approach addresses five main aspects: (i) heterogeneity among firms; (*ii*) variation and selection (in each firm there is a trade-off between *mechanisms of variation*, that is, mechanisms that introduce mutations into the characteristics of firms, and *mechanisms of selection*, that is, mechanisms that guarantee the global coherence); (*iii*) the learning process (guided by the search for better performance); and (*iv*) the continuous process of creation and shaping of knowledge (Cohendet, Llerena and Marengo, 1999 and 2000).

In turn, the Penrose theory of the growth of the firm stresses the interaction between resource-accumulating and organising processes (Ghoshal, Hahn and Moran, 2000) so that the firm’s ‘coherent administrative organisation’ determines the productivity level and its growth: “the growing experience of management, its knowledge of the other resources of the firm and of the potential for using them in different ways, create incentives for further expansion as the firm searches for ways of using the services of its own resources more profitably” (Penrose, 1995: p. xii). In short, firm productivity depends on the amount of resources but also on the efficiency with which they are used.

In our implementation, the model considers three stages of decision. In the first stage, we solve for firms’ output and profits and the market price, given the state of production techniques. In the second stage, firms decide about the technique to use in the next period. Finally, firms decide to continue, to exit or to enter in an industry.

We consider an industry with N price-taking firms producing a homogeneous output. A firm is too small to manipulate either output or input prices ($P_t \in \Re_+$ and $W_t \in \Re_+^n$, respectively). There are different techniques available in the industry, but they all share the following characteristics: (*i*) constant returns to scale; (*ii*) the same input coefficients $a_{jt} \in \Re_+$ (a_{jt} is the amount of input j necessary to produce one unit of output at time t); and (*iii*) Hicks neutral technical change (implying that the technical change leads to proportional reductions in all inputs, leaving the input mix unchanged). At time t, each firm uses only one technique, with output being determined by the full capacity. We also assume that input supplies are perfectly elastic and that input prices are constant over time.

Under these conditions, we can represent firm i's output at time t, q_{it}, by its composite input demand, X_{it}, times the total factor productivity, A_{it}, of the technique employed ($q_{it}, X_{it}, A_{it} \in \Re_+$), that is:

$$q_{it} = A_{it} X_{it} . \qquad (1)$$

where $X_{it} = a_t x_{it}$, $a_t \in \Re_+^n$ is the vector line of the technical coefficients of the industry and $x_{it} \in \Re_+^n$ is the vector column of firm i's input demand.

Given conditions (*i*), (*ii*) and (*iii*), the cost per unit of composite input, c, is constant across firms and over time. The firm's cost per unit of output is not the same across firms and over time because firms have different productivity levels and because productivity changes over time. The total cost of firm i at time t is given by:

$$c_{it} = \frac{c}{A_{it}} q_{it} . \qquad (2)$$

In an industry where firms have a price-taking behaviour and the techniques admit constant returns to scale, the only possible price policy is price equal to the average cost:

$$P_t = \frac{c}{A_t} , \qquad (3)$$

where A_t represents the (weighted) average productivity of the industry at time t. Thus, following an increase in the industry productivity, the market price will fall:

$$r = \frac{\dot{p}_t}{p_t} = -g_t , \qquad (4)$$

where g_t is the productivity growth rate of the industry at time t. (A dotted variable means variation over time.)

The short-run profit of firm *i* is equal to the price times the output minus the cost of production:

$$\pi_{it} = P_t q_{it} - \frac{c}{A_{it}} q_{it} \,. \tag{5}$$

The firm has profits if its productivity is higher than the (weighted) average of industry productivity, that is, if $A_{it} > A_t$. On the other hand, π_{it} increases if its productivity growth rate is higher than that of the industry:

$$\sigma = \frac{\dot{\pi}_{it}}{\pi_{it}} = \left(g_{it} - g_t\right)\frac{A_{it}}{A_t} \,, \tag{6}$$

where g_{it} represents the rate of productivity growth of firm i at time t.

The industry faces a downward sloping demand curve, $Q_t^D = D(P_t)$, with industry output given by $Q_t^S = \sum_{i=1}^{m_t} q_{it}$. The number of firms to operate in the industry at time *t* is determined by market demand and firm size:

$$m_t = \frac{D\left(c/A_t\right)}{q_t} \,, \tag{7}$$

where q_t represents the (weighted) average output per firm at time *t*.

The market share of firm *i*, $s_{it} = q_{it} / Q_t^S$, is the chosen measure of firm's size. Thus, the growth rate of firm size is given by:

$$\alpha_{it} = \frac{\dot{s}_{it}}{s_{it}} = g_{it} - g_t \,, \tag{8}$$

that is, a firm increases its size if its output growth rate is higher than that of the industry $(g_{it} > g_t)$.

Evolutionary models stress the importance of heterogeneity among firms (e.g. Nelson, 1994; Fransman, 1998; and Cohendet, Llerena and Marengo, 1999 and 2000). In these models, the members of a population have only some attributes in common (Metcalfe, 1998). Thus, because they have different techniques, that is, different production routines, they will have different productivity levels.

The production routines represent the group of routines directly concerned with the production process and determine the characteristics of the output and the efficiency of the firm[1]. Each firm employs one technology at each time. Although all firms in the industry face the same set of technologies, there is no reason to expect that firms will choose the same technology. There are two reasons: first, at any time, new technological alternatives compete with the old ones, with considerable *ex ante* uncertainty about which one will be the most productive (Nelson, 1998); second, firms with the same technological information may behave differently because they have different past experiences or because different expectations lead them to interpret that information differently (Metcalfe, 1997 and 1998).

Productivity across firms also differs because they have different organisational routines (each firm has its own organisational design attributes). Thus, two firms with the same technology can use it with different efficiency because their organisational routines are different (Rumelt, 1995).

We define firm's productivity level at time t as:

$$A_{it} = A_t^k u_{it}\,, \tag{9}$$

where (A_t^k) is the highest productivity level of the chosen technology, (u_{it}) is the firm's efficiency level of firm *i*, and $0 < u_{it} \leq 1$.[2]

Having solved the first stage, the firm will take two new decisions. First, it has to decide about the technique to use in the next period. Second, it has to decide whether to continue or exit the industry.

The firm's technology in period *t*+1 depends on the firm's decision to invest or not in new technologies in period *t*. A firm becomes more productive by innovating or by imitating the production processes of other firms. For simplicity, we assume that either method involves the same R&D expenditures, c_K, and that each investment decision in innovation or imitation has the same effect on firm's productivity, namely it raises *A* at rate *g*, that is:

$$A_{i(t+1)}^k = A_0^k e^{tg}\,. \tag{10}$$

We note that t does not record calendar; it increases every time an investment in new technologies occurs, not necessarily every period. g represents the rate of productivity growth associated with technological change. The firm's decision to invest or not in new

[1] This group of routines are related as much with matters of organisation as with the technology (Metcalfe, 1998).

[2] For a theoretical explanation on the determination of the productivity growth due to changes in efficiency and technological change see Grosskopf (1993); for empirical estimates, see Fecher and Pestieau (1993) and Nishimizu and Page (1982), inter al.

technologies depends on the firm's productivity expectation and on R&D expenditures. We assume that the goal of all firms is to choose the highest net present value, and that the period where the decision to invest is taken is $t = 0$. The new technology is used at the beginning of period 1. A firm will decide to invest if the net present value when it invests (V_{i0}^{I}) is higher than the net present value when it does not invest (V_{i0}). The net present value of an active firm that decides to continue in the industry is given by:

$$V_{i0} = p_{i0} + \int_{t=1}^{T} e^{-rt} E(p_{it}) dt \,, \tag{11}$$

where p_{i0} is the profit in period 0, $E(p_{it})$ is the expected profit in period t, and r is the discount rate.

If the firm decides to invest, it will have to support the R&D expenditures but, given (10), its productivity will be larger. The net present value of an active firm that decides to invest in period 0 is given by:

$$V_{i0}^{I} = p_{i0} + \int_{t=1}^{T} e^{-rt} E(p_{it}^{I}) dt - c_K \,, \tag{12}$$

where $E(p_{it}^{I})$ is the expected profit when the firm invests. A producer will decide to invest if $V_{i0}^{I} > V_{i0}$. Using (11) and (12), an active firm will decide to invest if the increase in the expected discounted profits is higher than c_K:

$$\int_{t=1}^{T} e^{-rt} E(p_{it}^{I}) dt - \int_{t=1}^{T} e^{-rt} E(p_{it}) dt > c_K \,. \tag{13}$$

If we assume that the expected profits are constant over time (that is, $E(p_{it}) = E(p_{i0}), \forall t$), and that the firm expects the profit growth rate $\hat{s}$ when there is investment, then $E(p_{it}^{I}) = e^{\hat{s}} E(p_{it})$. Therefore, condition (13) yields [appendix 1]:

$$e^{\hat{s}} > 1 + \frac{re^{r} c_K}{E(p_{i0})} \,. \tag{14}$$

Firms can also increase the productivity by improving the efficiency of organisational routines. Learning and adapting over time is very important in the evolutionary approach, but routines are usually hard to change, being responsible for inflexibility and inertia in organisational behaviour (Cohendet, Llerena and Marengo, 1999; Rumelt, 1995).

The firm's knowledge is copied and transmitted over time and in this process new knowledge is incorporated through innovation and imitation and, as a result, the routines changed. Thus the efficiency of the firm's organisational routines increases over time with the learning process. We assume however that the access to the new information necessary for acquisition of new organisational knowledge has a zero cost.

As time goes by, firms improve their organisational knowledge and their efficiency. The capacity of changing the organisational routines varies however across firms and over time, and this is due to the fact that firms learn differently from the past (Nelson and Winter, 1982). Thus, a firm that is more efficient than another in a certain period can have its position reversed in the following periods.

When a firm invests in new technologies it also changes its organisational routines and its efficiency. For example, firms need some time before using a new technology at its maximum potential. Thus, firm efficiency at each time can be written as:

$$u_{i(t+1)} = (1-t)\, u_{it} e^{h_{i(t+1)}} + t\; u^{k}_{i(t+1)} + e_{i(t+1)}\,, \qquad (15)$$

where h_{it} represents the rate of productivity growth associated with the efficiency improvement, $u^{k}_{i(t+1)} \in \left]0,1\right]$ the new firm's efficiency when it invests in technology *k*, and e_{it} is a random term. We assume $t = 1$ if the firm invests, and $t = 0$ otherwise. There is however a limit for efficiency improvements as $\lim_{t\to\infty} u_{it} = 1$, and therefore $h_{it} = 0$ if $u_{it} = 1$.

Considering (9), (10), and (15), and assuming that the growth of demand for inputs is zero, the output growth rate is equal to the productivity growth rate, that is:

$$g_{it} = t\left(g + \frac{u_{i(t-1)} - u^{k}_{it}}{u_{i(t-1)}} \right) + (1-t)h_{it}\,. \qquad (16)$$

Thus, the output growth rate can be decomposed in two components. The first corresponds to the output growth if the firm decides to invest. It represents the productivity growth rate associated with the technological change, minus the change of the efficiency due to the introduction of new technology. The second component is the productivity growth rate due to the efficiency growth.

Finally, in each period, active firms must decide to continue or to exit the industry, and the potential entrants should decide whether to enter or not. There are entry and exit barriers associated with the structural characteristics of the industry, defined by vector *B*. However, these barriers are not too much high to preclude the entry and exit of firms. In the model we represent the barriers in terms of entry and exit costs, $c_E(B)$ and $c_X(B)$, respectively. The entry and exit costs are increasing with the level of barriers ($\partial c_E / \partial B > 0$ and $\partial c_X / \partial B > 0$).

The exit decision is taken in period 0, but it is implemented at the beginning of period 1. The net present value of an active firm that decides to exit is given by:

$$V_{i0}^X = p_{i0} - c_X(B). \tag{17}$$

An active firm will decide to continue in the industry if $V_{i0} \geq V_{i0}^X$. Using (11) and (17), a producer will decide to continue in the industry if positive profits are expected ($E(p_{i0}) > 0$) or if the absolute value of expected discounted losses (negative profits) are lower than the exit cost:

$$\left| \int_{t=1}^{T} e^{-rt} E(p_{it}) dt \right| \leq c_X(B). \tag{18}$$

Considering the condition established in (14), condition (18) yields [appendix 2]:

$$\left| E(p_{i0}) \right| \leq re^r c_X , \tag{19}$$

with $E(p_{i0}) < 0$. The exit condition (19) admits a critical point for the expected loss $E(p_{i0}^*) = -re^r c_X$ and the expected productivity $E(A_{i0}^*) = [\ 1 - (re^r c_X / cX_{i0})\ ] A_0$. If the expected productivity (or the expected profit) of firm *i* is higher than the critical point, then it decides to stay; otherwise, firm *i* decides to exit. When the exit barriers are low, the exit cost is also low. In this case, the surviving firms are the most productive, given that $E(A_{i0}^*)$ is high. If the exit barriers are high, firms with lower productivity will remain active, given that $E(A_{i0}^*)$ is also low. In this case higher productivity firms will coexist with less productive ones.

Now we define the entry conditions. Whether a potential entrant becomes an actual entrant depends on the evaluation of the profit opportunities generated by the technology of entry. Entry decision is taken in period 0, and the entry is made at the beginning of period 1. The net present value of a potential entrant is given by:

$$V_{i0}^E = \int_{t=1}^{T} e^{-rt} E(p_{it}) dt - c_E(B). \tag{20}$$

A potential entrant decides to enter in the industry if $V_{i0}^E > 0$, that is, if its expected discounted profits are higher than the entry cost:

$$\int_{t=1}^{T} e^{-rt} E(p_{it}) dt > c_E(B). \tag{21}$$

Using the condition established in (14), condition (21) yields [appendix 3]:

$$E(p_{i0}) > re^{r} c_E \,. \qquad (22)$$

The entry condition (22) also admits a critical point for the expected profit $E(p_{i0}^{**}) = re^{r} c_E$ and the expected productivity $E\left(A_{i0}^{**}\right) = \left[\ 1 + \left(re^{r} c_E / cX_{i0}\right)\ \right] A_0$. If the expected productivity (or the expected profit) for firm *i* is higher than the critical value, the firm decides to enter, otherwise it decides to stay away. When the entry barriers are high the entry cost is also high. In this case firms need to anticipate a high discounted profit in order to decide to enter. They will have therefore a high expected productivity, given that $E\left(A_{i0}^{**}\right)$ is high. If the entry barriers are low the entry decision are taken with low productivity and expected discounted profit, given that $E\left(A_{i0}^{**}\right)$ is also low.

Using (19) and (22), those firms that decide to enter will have a larger expected efficiency than the ones that exit, given that the critical productivity of exit is lower than the critical productivity of entry ($E\left(A_{i0}^{*}\right) < E\left(A_{i0}^{**}\right)$).

Based on (19) and (22), if the entry and exit barriers are high, there will be few firms to enter and to exit. On the one hand, few potential entrants will take the decision to enter, because the critical expected productivity of entry is higher. On the other hand, few active firms will actually exit, because the critical expected productivity of exit is low. When B is small there will be a large number of firms to enter and exit. In any case, both entry and exit will be observed.

3. Simulation Results

In this section we summarise the results of the simulation exercise using the LSD (Laboratory for Simulation Development) software.[3] We focus on the impact of entry and exit costs and demand growth on industrial competition, assuming nine possible combinations of barriers (medium, high, and low) and market demand growth (demand elasticity equal to 1 and lower and greater than 1). In order to generate the dynamic properties of the model, we have run 100 simulations in each of the nine cases reported in Table 1.

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[3] LSD is a friendly simulation tool developed by Marco Valente for IIASA, Austria, and for IKE/DRUID, Aalborg University, Denmark. Presently the LSD project is hosted by IKE and DRUID, Aalborg University.

The initial values of the parameters used in the simulation are presented in Appendix 4. Four different initial technologies and differences in firms' inefficiencies were considered. For the determination of the expected rate of profit growth, we used a model of adaptive expectations with short memory. Full model implementation is provided in the Appendix.

Figure 1 plots the evolution of the population of firms. As expected, the number of firms, N, depends critically on the demand growth assumption: N is virtually constant in cases 11, 12, and 13; increasing in cases 21, 22 and 23; and decreasing in cases 31, 32 and 33. The fluctuation in the number of firms is also stronger when the barriers are low. In the elastic demand case, the number of firms is higher when the barriers are low (120 firms in the final period; 103 firms when the barriers are high), while in the inelastic demand case, the number of firms is higher when the barriers are high (24 firms; 15 firms when the barriers are low). It seems therefore that when the market demand increases more than proportionally the low barriers allow the entry of more firms; when the market demand increases less than proportionally the high barriers hamper the exit of the firms.

Table 2 displays the average and final period results in each of the nine configurations. Firstly, there is a significant difference in entry and exit rates. We confirm that the lowest entry and exit average rates, 0.1% and 0.6%, occur in case 32 (inelastic demand and high barriers), while the elastic demand and low barriers case shows the highest entry and exit rate, 7.9% and 7.4%, respectively. Confirming our priors, and irrespective of the assumption on market demand, the entry and exit rates are higher when the barriers are low. It seems therefore that the selection mechanism is more active in the case of low barriers. When the market demand is elastic the entry rate is higher than the exit rate, while when the market demand is inelastic the entry rate is lower than the exit rate. These results explain the difference in the number of firms reported in the final period.

Given that the R&D expenditures are the same in all scenarios, the differences in the rate of investment in new technologies can only be due to different profit expectations. As Table 2 shows, the investment rate is higher when the barriers are high, which implies an average productivity lower than in the case of low barriers because the selection mechanism is weaker (Figure 2). In the inelastic demand case, the investment rate is also higher when the barriers are not low, which means that in such cases firms, in order to survive, need to invest more because the selection process is stronger (the number of firms decreases from 42 to 16 in case31 and to 24 in case 32).

Figure 2 plots the weighted average productivity in each configuration. As can be seen, productivity increases over time in all cases. Moreover, irrespective of demand elasticities the productivity growth is higher when the barriers are low. In the final period, the elastic demand case presents the highest average productivity.

As explained by equation (4), productivity moves in opposite direction of the price. We can confirm this relation comparing Figures 2 and 3, where the market price decreases in all configurations. In the final period, the high barrier configurations (with elastic and inelastic market demand) show the lowest prices.

We also expect from the model that the productivity of entry firms will be higher than the productivity of exiting firms. Figure 4 confirms this prediction, as the productivity of entry firms is always higher than the productivity of exiting firms.

Finally, Figure 5 shows that the efficiency growth impacts the rate of productivity growth. In all cases, the plots of productivity growth and efficiency growth have the same pattern. Thus, the changes in efficiency contribute decisively to changes in total productivity.

5. Conclusion

In this paper we have proposed a model based on the evolutionary theory, where an explicit relationship between productivity, efficiency, and mobility of firms is established. We have built a dynamic model with N price-taking firms that endogenously determine the process of entry, exit, and growth. The technology and the productive efficiency differ among firms initially and the selection process maintains this hypothesis over time. The simulation exercise, which also assumes different levels of entry and exit barriers (and market demand growth), suggests that firms can only survive in the market by continuously introducing new technologies and improving the efficiency.

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Appendix 1: Investment condition

$$V_{i0}^{I} > V_{i0} \Leftrightarrow p_{i0} + \int_{t=1}^{T} e^{-rt} E\left(p_{it}^{I}\right) dt - c_K > p_{i0} + \int_{t=1}^{T} e^{-rt} E\left(p_{it}\right) dt \Leftrightarrow$$

$$\Leftrightarrow \int_{t=1}^{T} e^{-rt} E\left(p_{it}^{I}\right) dt - \int_{t=1}^{T} e^{-rt} E\left(p_{it}\right) dt > c_K .$$

If $E\left(p_{it}\right) = E\left(p_{i0}\right)$ and $E\left(p_{it}^{I}\right) = e^{\hat{s}} E\left(p_{it}\right) \Rightarrow$

$$\Rightarrow \int_{t=1}^{T} e^{-rt} e^{\hat{s}} E\left(p_{i0}\right) dt - \int_{t=1}^{T} e^{-rt} E\left(p_{i0}\right) dt > c_K \Leftrightarrow \left(e^{\hat{s}} - 1\right) E\left(p_{i0}\right) \int_{t=1}^{T} e^{-rt} dt > c_K \Leftrightarrow$$

$$\Leftrightarrow \left(e^{\hat{s}} - 1\right) E\left(p_{i0}\right) \frac{1}{re^{r}} > c_K \Leftrightarrow e^{\hat{s}} > \frac{re^{r} c_K}{E\left(p_{i0}\right)} + 1 .$$

Appendix 2: Production condition

$$V_{i0} \geq V_{i0}^{X} \Leftrightarrow p_{i0} + \int_{t=1}^{T} e^{-rt} E\left(p_{it}\right) dt \geq p_{i0} - c_X\left(B\right) \Leftrightarrow$$

$$\Leftrightarrow \int_{t=1}^{T} e^{-rt} E\left(p_{it}\right) dt \geq -c_X\left(B\right) \Leftrightarrow -\int_{t=1}^{T} e^{-rt} E\left(p_{it}\right) dt \leq c_X\left(B\right).$$

Therefore,

if $\int_{t=1}^{T} e^{-rt} E\left(p_{it}\right) dt \geq 0$, the firm to continue for any value of c_X;

if $\int_{t=1}^{T} e^{-rt} E\left(p_{it}\right) dt < 0$, the firm to continue if $\left| \int_{t=1}^{T} e^{-rt} E\left(p_{it}\right) dt \right| \leq c_X\left(B\right) \Leftrightarrow$

$$\Leftrightarrow \left| E\left(p_{i0}\right) \int_{t=1}^{T} e^{-rt} dt \right| \leq c_X\left(B\right) \Leftrightarrow \left| E\left(p_{i0}\right) \frac{1}{re^{r}} \right| \leq c_X\left(B\right) \Leftrightarrow \left| E\left(p_{i0}\right) \right| \leq re^{r} c_X\left(B\right)$$

Appendix 3: Entry condition

$$V_{i0}^{E} > 0 \Leftrightarrow \int_{t=1}^{T} e^{-rt} E\left(p_{it}\right) dt - c_E\left(B\right) > 0 \Leftrightarrow E\left(p_{i0}\right) \int_{t=1}^{T} e^{-rt} dt > c_E\left(B\right) \Leftrightarrow$$

$$\Leftrightarrow E\left(p_{i0}\right) \frac{1}{re^{r}} > c_E\left(B\right) \Leftrightarrow E\left(p_{i0}\right) > re^{r} c_E\left(B\right).$$

Appendix 4: Initial values

(*i*) Parameters:

Initial number of firms: m = 42;

Demand coefficient: D = 67;

Demand elasticity: ε_1 = 1.0; ε_2 = 1.3; ε_1 = 0.7;

Production cost per unit of input: c = 0.16;

Input demand per firm: X = 10;

R&D expenditures: c_K = 13.5;

Entry and exit costs: medium barriers: $c_E = c_X$ = 6.0; high barriers: $c_E = c_X$ = 6.85;

low barriers: $c_E = c_X$ = 5.15;

Discount rate: r = 0.1;

Rate of productivity growth associated with technological change: g = 0.04;

Rate of productivity growth associated with the efficiency improvement: h = 0.015;

Standard deviation of technological productivity of new firms: σ = 0.015.

(*ii*) Technology space:

Initial productivity levels of four (0.368, 0.336, 0.304, and 0.272) technologies:

A_0^k = {0.368, 0.368, 0.368, 0.368, 0.368, 0.368, 0.368, 0.368, 0.368, 0.368, 0.368, 0.336, 0.336, 0.336, 0.336, 0.336, 0.336, 0.336, 0.336, 0.336, 0.336, 0.336, 0.304, 0.304, 0.304, 0.304, 0.304, 0.304, 0.304, 0.304, 0.304, 0.304, 0.272, 0.272, 0.272, 0.272, 0.272, 0.272, 0.272, 0.272, 0.272, 0.272};

Initial efficiency levels:

u = {0.6107, 0.5986, 0.5879, 0.5785, 0.5701, 0.5627, 0.5561, 0.5502, 0.545, 0.5403, 0.5361, 0.6107, 0.5986, 0.5879, 0.5785, 0.5701, 0.5627, 0.5561, 0.5502, 0.545, 0.5403, 0.5361, 0.6107, 0.5986, 0.5879, 0.5785, 0.5701, 0.5627, 0.5561, 0.5502, 0.545, 0.5403, 0.6107, 0.5986, 0.5879, 0.5785, 0.5701, 0.5627, 0.5561, 0.5502, 0.545, 0.5403}.

Table 1: Simulation cases

		Barriers		
		Medium	High	Low
Elasticity of Market demand	$\varepsilon_1 = 1.0$	Case 11	Case 12	Case 13
	$\varepsilon_2 = 1.3$	Case 21	Case 22	Case 23
	$\varepsilon_1 = 0.7$	Case 31	Case 32	Case 33

Figure 1: Number of Firms

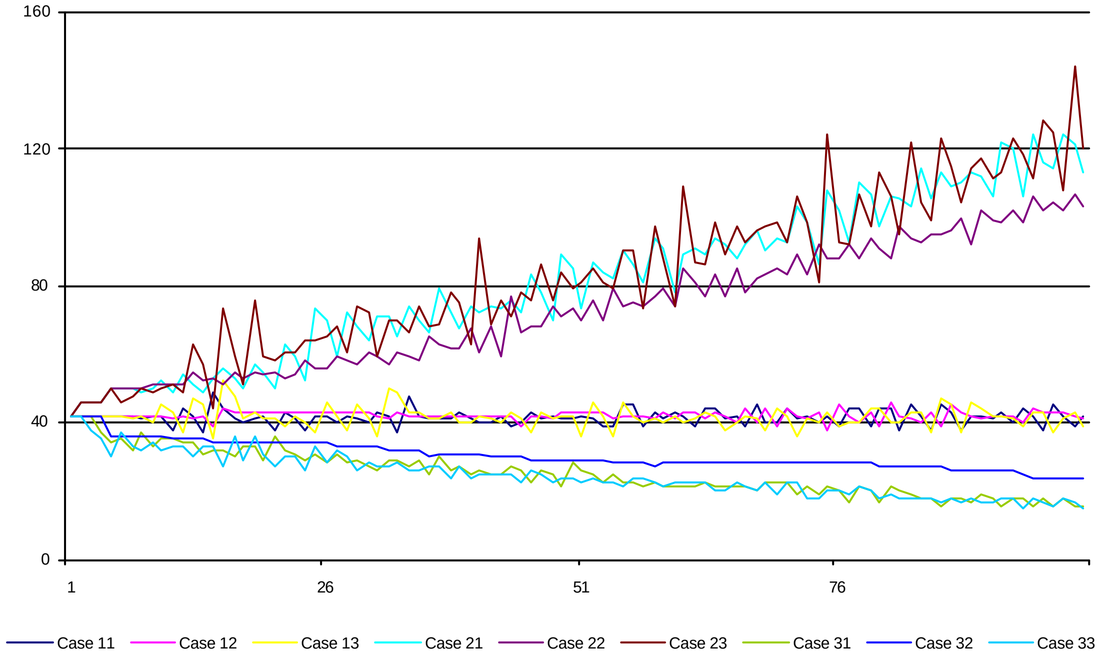


Table 2: Average and Final Period Results

		Case 11	Case 12	Case 13	Case 21	Case 22	Case 23	Case 31	Case 32	Case 33
Population	Average	42	42	42	81	73	83	25	30	25
	Final period	42	41	39	113	103	120	16	24	15
Number of entrants	Average	2	1	2	5	3	7	1	0	1
	Final period	5	0	0	2	0	0	1	0	0
Number of exits	Average	2	1	2	4	2	6	1	0	1
	Final period	2	1	4	10	4	24	1	0	2
Number of investments in new technologies	Average	15	16	15	28	27	29	10	13	8
	Final period	11	10	7	32	39	55	4	7	2
Entry rate	Average	4.3%	1.7%	4.9%	5.6%	3.6%	7.9%	3.6%	0.1%	4.6%
	Final period	11.9%	0.0%	0.0%	1.8%	0.0%	0.0%	6.3%	0.0%	0.0%
Exit rate	Average	4.4%	1.7%	5.2%	4.9%	2.8%	7.4%	4.5%	0.6%	5.7%
	Final period	5.1%	2.4%	9.3%	8.3%	3.7%	16.7%	6.3%	0.0%	11.8%
Rate of investment in new technologies	Average	34.9%	37.3%	34.9%	34.9%	36.8%	34.2%	36.9%	41.6%	31.7%
	Final period	26.2%	24.4%	17.9%	28.3%	37.9%	45.8%	25.0%	29.2%	13.3%

Figure 2: Average Productivity

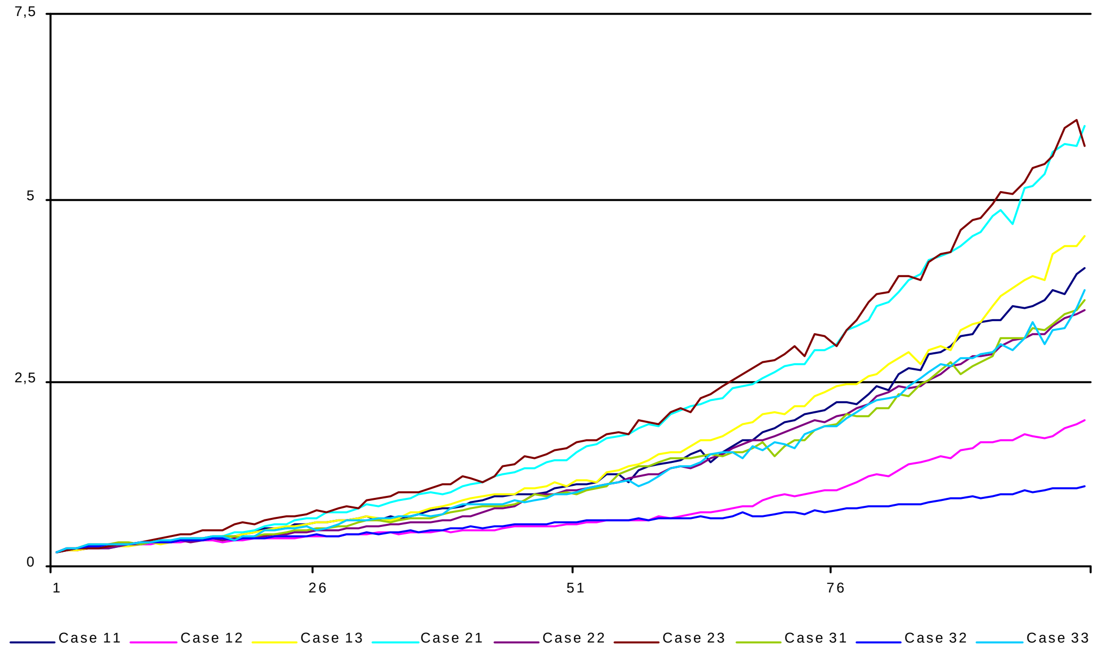


Figure 3: Price evolution

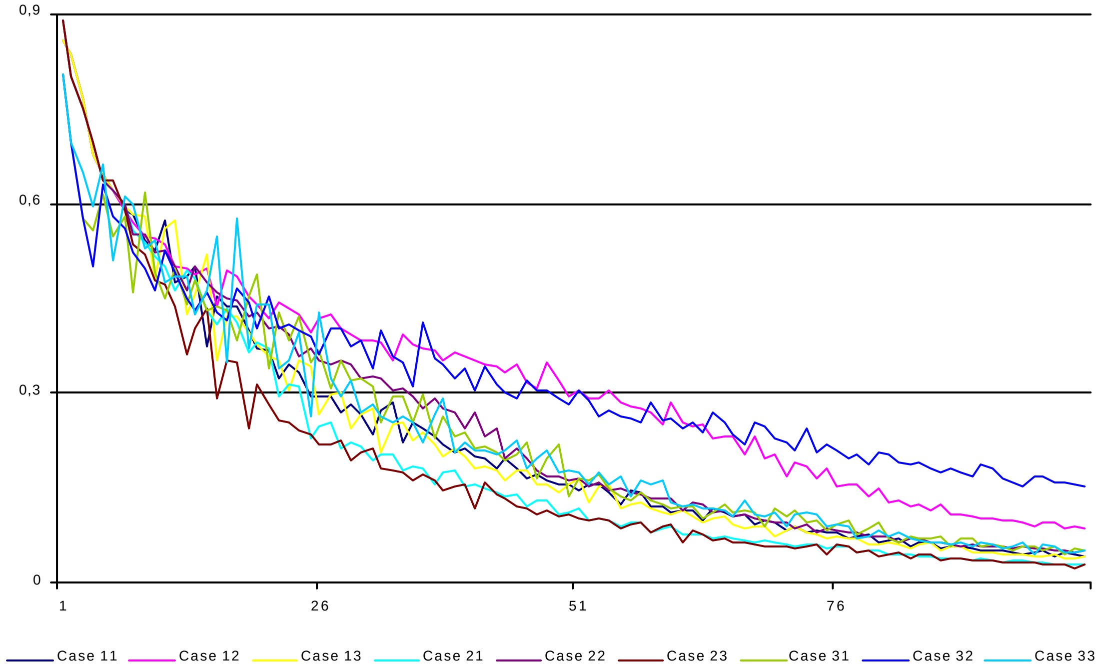


Figure 4: Average Productivity of Continuing, Entrants and Exiting Firms (case 11)

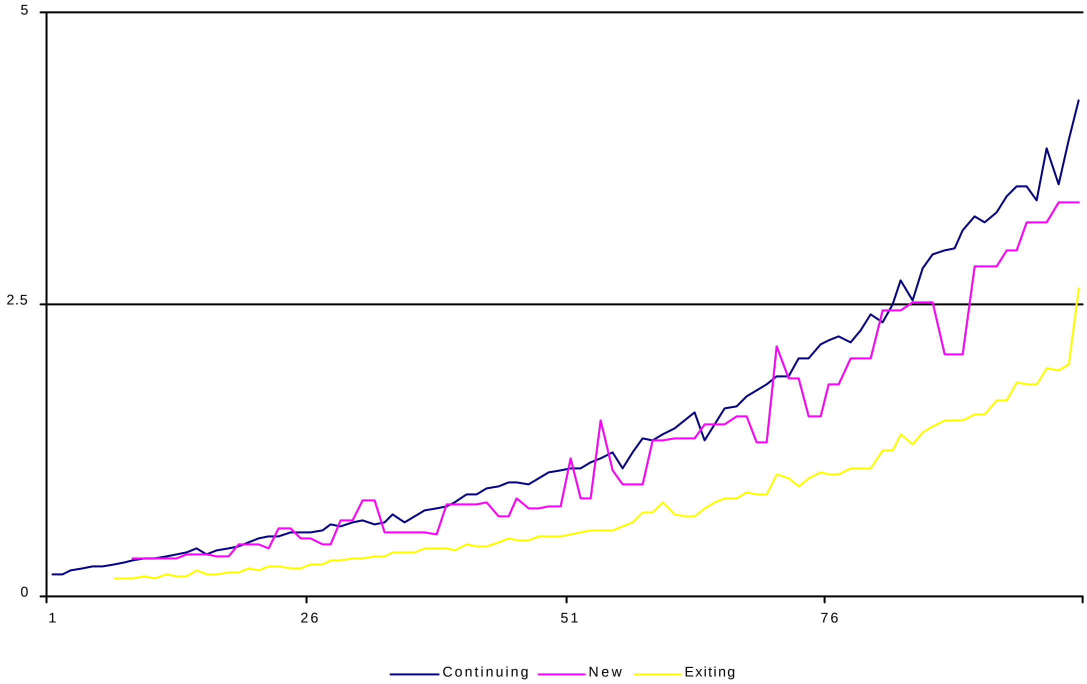
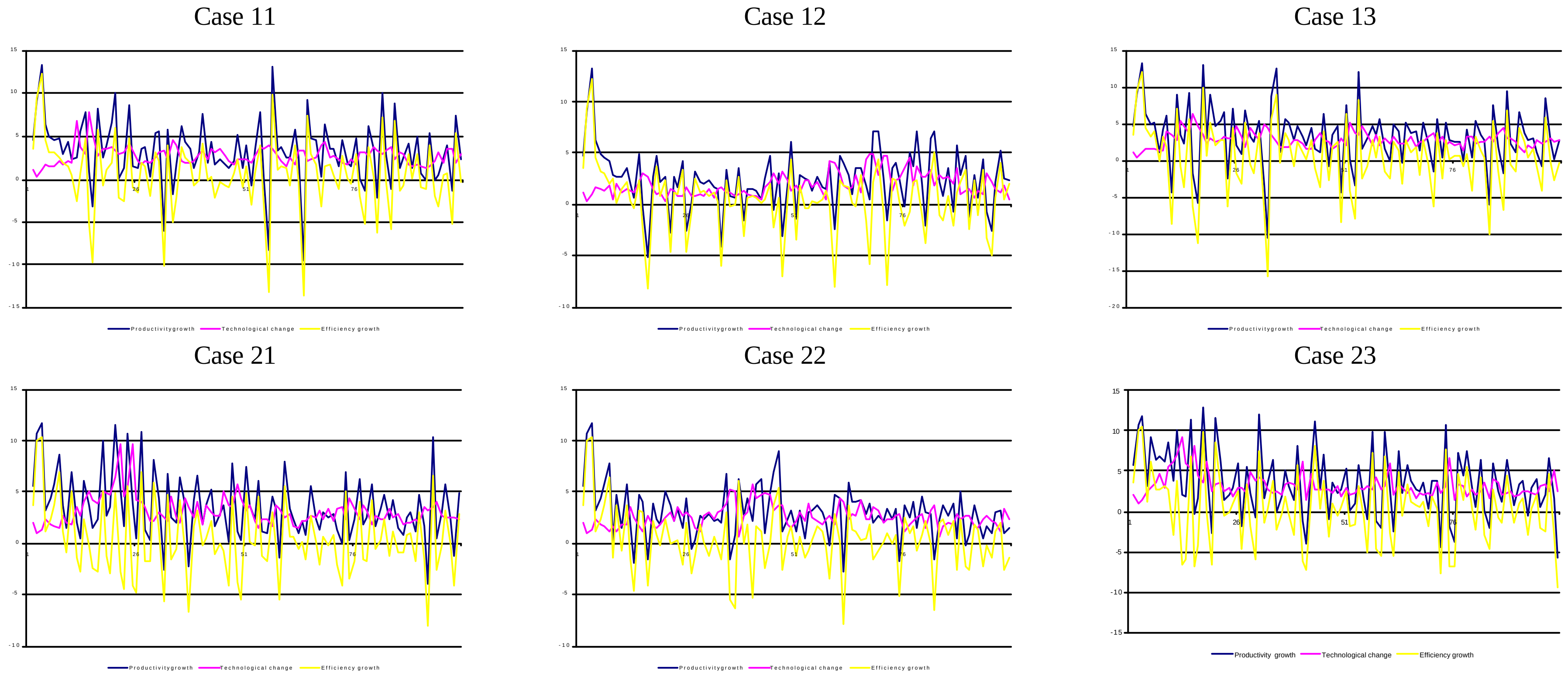
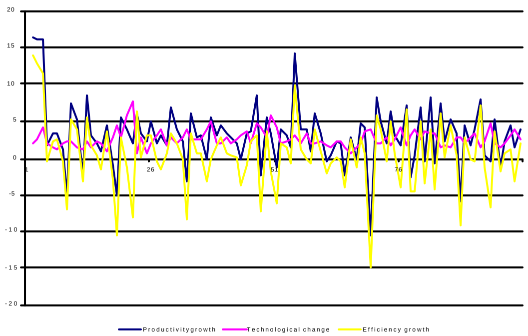


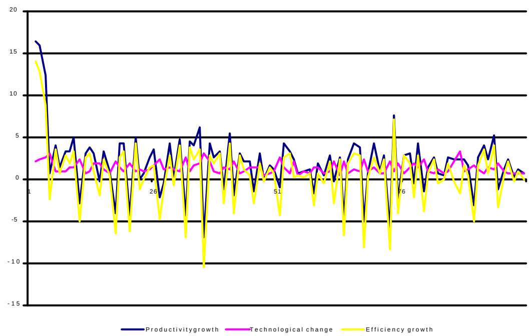
Figure 5: Components of Productivity Growth



Case 31



Case 32



Case 33