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Entry and exit as a source of aggregate productivity growth in two alternative technological regimes

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Entry and exit as a source of aggregate productivity growth in two alternative technological regimes

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Abstract

This paper proposes a neo-Schumpeterian model in order to discuss how the mechanisms of entry and exit contribute to industry productivity growth in alternative technological regimes. By assuming a) that firms learn about the technology through a variety of sources, and b) a continuous flow of entry and exit, our numerical simulation exercise does show that exits and contraction take mostly place among less productive firms, while entry and expansion are concentrated among the more efficient ones. We were also able to replicate the fact that the entry-exit effect is larger in the entrepreneurial regime, while the contribution of continuing firms is larger in the routinized regime. Our model was thus very effective in replicating some major empirical regularities of industry dynamics, including the very prominent role of entry and exit in productivity growth. Our analysis also suggests that micro analysis is the proper complement to aggregate industry studies, as it provides a considerable insight into the causes of productivity growth.

Keywords: Entry and Exit; Industrial Dynamics; Learning; Productivity growth; Nelson-Winter evolutionary industry model.
JEL classification: L1, D24, O3, C63.

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"Developing the conceptual models of heterogeneity in behavior, reallocation, and lumpy adjustment at the micro level and, in turn, considering the aggregate implications, should be a high priority."

Foster, Haltiwanger and Krizan (2001)

1. Introduction

In the past few years the study of productivity issues has greatly shifted towards the understanding of the operation of micro units, with a particular emphasis on establishment (firm)-level reallocation. It is indeed believed that a large percentage of aggregate (industry) productivity growth can be solely imputed to mobility of firms, with low-productivity firms losing market share (or shutting down) in favour of more productive incumbents and new entrants.

This study proposes a neo-Schumpeterian model in which the role of firm dynamics on industry evolution is extensively modelled. In a new departure from the original Nelson-Winter evolutionary industry model (Nelson and Winter, 1982; and Winter, 1984), which was mostly focused on technological change, we examine how the mechanisms of entry and exit contribute to industry productivity growth. A central hypothesis in our approach is that the aggregate productivity growth of an industry is driven by the development of micro units, and that the changes in productivity of individual firms are non uniform, which leads to strong heterogeneity across firms and to an intense mechanism of entry and exit.

One key aspect of our modelling is the full characterization of the technological regime in which firms operate. Two raw cases are considered: the 'routinized regime' and the 'entrepreneurial regime'. We develop a competitive dynamic framework of an industry composed by heterogeneous firms and by continuing entry and exit. The learning process can take different forms. Following the taxonomy proposed by Malerba (1992), firms can learn through 'learning by doing' and 'learning by using' on the one hand, and 'learning by searching' and 'learning from external sources' on the other.

The paper is organised as follows. Section 2 offers a brief review of the empirical literature on firm entry and exit and on firm productivity dynamics. Section 3 develops a neo-Schumpeterian model of industrial dynamics. Section 4 implements Lsd numerical simulations, with a particular emphasis on the sensitivity analysis of the results with respect to key model parameters. The main goal of the exercise is to evaluate to what extent our modelling strategy can replicate some stylized facts on industry dynamics and productivity growth summarized in Section 2. Section 5 contains the concluding remarks.

The numerical simulation exercise shows that exits and contraction take mostly place among less productive firms, while entry and expansion are concentrated among the more efficient ones. It is therefore quite clear that firm mobility plays a substantial role on aggregate productivity growth. We were also able to replicate the fact that the entry-exit effect is larger in the entrepreneurial regime, while the contribution of continuing firms is larger in the alternative (routinized) regime. To summarize, it seems that our modelling strategy was very effective in replicating some major empirical regularities of industry dynamics, including the very prominent role of entry and exit on aggregate productivity growth.

2. Firm dynamics and industry productivity growth: some facts

Studies in several countries indicate that entry and exit flows of firms are very substantial (Caves, 1998; Geroski, 1995). In the U.K. manufacturing sector, for example, the (annual) entry and exit rates were about 6.5% and 5.1%, respectively, in the period 1974-79. In Canada, between 1970 and 1982, the corresponding rates were 4.9 and 6.5%. Moreover, these rates vary substantially across industries – for example, the entry rate fluctuated from 3.5% to 9.6% across the U.K. (two-digit) sectors.

Entry and exit also tend to be highly positively correlated. The main reason is of course that the rate of early mortality is very high for entrants. In Canada, the hazard rate for 1971 entrants was about 10% at the end of the first year (roughly, twice as much as for incumbent firms). In the U.K., 19% of new firms established in 1974 exited within the following two years, while 51% did not survive longer than five years (Geroski, 1991; Baldwin, 1995).

In contrast, the growth rate among successful entrants is very high. On average, surviving new plants double their initial size after six to seven years (Mata *et al*., 1995), although successful entrants may take more than a decade to achieve the average size of established firms (Audretsch and Mata, 1995).[1]

The relationship between industry dynamics and firms' characteristics (e.g. size, age, technological environment, and innovation) is also an important one (Geroski, 1995; Caves, 1998). The technological environment, for example, seems to impact the entry rate, while profits do not (Geroski, 1994; Dosi and Lovallo, 1997). Acs and Audretsch (1990) and Geroski (1994) have observed a positive (although modest) correlation between entry and innovation rates, suggesting that a more innovative environment encourages entry. Indeed, entry seems to be more intense in an environment providing potential entrants with greater opportunities to innovate, while the greater is the total amount of innovative activity and intensity of R&D, the higher seems to be the entry barriers. Audretsch and Acs (1994) observed, in particular, that the entry rates were lower among prototypal routinized regime industries than among industries characterized by the entrepreneurial regime.[2]

The influence of technological environment and innovation on the ability of new firms to survive has also been examined in the literature. Audretsch (1991), using the United States data on new manufacturing firms (i.e. created in 1976), found that an increase in the capacity of small and new firms to innovate leads to a higher survival rate, especially in the entrepreneurial regime. In the routinized regime, where the ability of small firms to innovate is relatively low, the survival rate tends to be smaller. Another important regularity is that firm's growth rate decreases with size and age, while survivability increases with the same arguments (Bottazzi and Secchi, 2003; Evans, 1987).

The technological environment influences market turbulence (i.e. market share instability) as well (Dosi et al., 1995). For U.S. firms (1976-80), Audretsch and Acs (1990) found that turbulence was higher in industries characterised by the entrepreneurial regime. Turbulence was

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[1] An entrant is typically very small – in the United States, for example, an entrant over the period 1963-82 only produces in the entry year, on average, 35.2% of the incumbents' output level (Dunne *et al.*, 1988).

indeed higher in industries where small firms were able to implement a strategy of innovation and lower in industries where they were less able to innovate. Davies and Geroski (1997) in turn observed that turbulence in the top five U.K. firms (in 1979 and 1986) tend to increase with R&D intensity, but the characteristics of this specific sample of firms make the comparison a difficult one. Surprisingly enough, Audretsch and Acs (1990) found that there is more, not less, turbulence in concentrated industries.[3]

Finally, the dynamics of firms is expected to lead to a higher aggregate productivity growth, with changes in industry-level productivity arising either from within-firm productivity growth (for example, due to technological changes or human capital improvements), or from resource reallocation (i.e. entry and exit of firms; see Carreira and Teixeira, 2008). Baily et al. (1992), for example, found that the contribution of increasing output shares of high-productivity continuing plants was the most important source of the U.S. industry productivity growth, while the entry-exit effect was found to be very small. For its part, Foster, Haltiwanger and Krizan (2001) found that net entry plays a significant role in the medium and long term, with resource reallocation accounting for half of manufacturing productivity growth, of which about 18% was due to the net entry effect. These results were corroborated by Baldwin (1995) who has shown that, in the 1970s, firm dynamics contributed substantially to the Canadian (labour) productivity growth – around 40% to 50% of productivity growth was estimated to have been due to firm dynamics, with 37% of the employment share being transferred from exiting and contracting plants to entering and expanding plants.[4]

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[2] The full definition of technological regimes is given in Section 3 below.

[3] For a given concentration index, more turbulence suggests the presence of a higher degree of competition.

[4] The role of firm mobility on productivity growth was not confirmed, for example, by Griliches and Regev (1995). Their analysis of Israeli industry (1979-88) shows that a larger proportion of aggregate labour productivity growth is due to productivity changes within firms rather than to their mobility. It is nevertheless worthwhile mentioning that the time period considered is much shorter (three-year periods in their analysis).

3. The model

The empirical regularities outlined in the previous section are at the root of our modelling strategy. Our model draws on Nelson-Winter evolutionary industry model (1982: ch. 12; Winter, 1984), with two main novelties: *a*) a greater focus on the learning process – firms can learn about technology through a variety of sources: 'learning by doing', 'learning by using', 'learning by searching', and 'learning from external sources'; Malerba, 1992; and *b*) a more direct and detailed modelling of entry and exit of firms.

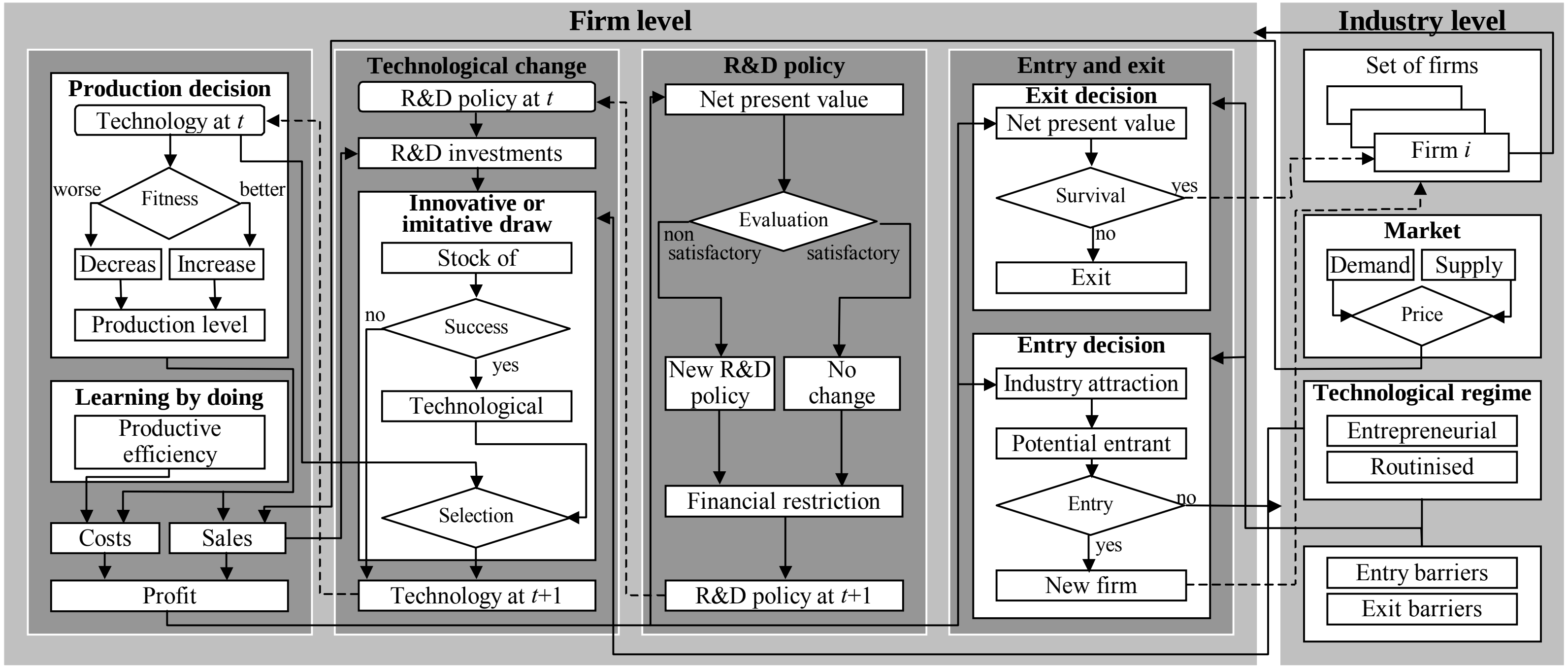
Let us assume, at time 'zero', a 'mature' industry made up of a finite number of competitors producing a single and homogeneous product. All individual technologies exhibit constant returns to scale, with output equal to full capacity. Input supplies are perfectly elastic and input pries are exogenously given and constant over time.

Figure 1 shows the main structure of the model. In each period the state of production technologies across firms determine the output level and the market price. Then, once firms R&D investment is made (and assuming their R&D activities are successful in innovating or imitating), they decide whether to stick with the current technology or engage on technological changes in the next period. Once firms learn about their performance, they decide firstly on the future R&D effort and secondly whether to continue or exit, while new firms enter in the market.

3.1. Production, costs and profits

Given product homogeneity, firms choose quantities rather than prices. Quite naturally, more productive firms (i.e. with a competitive cost advantage) are expected to gain market share, while less productive firms will be expected to lose market share (or forced to exit).

Figure 1: Structure of the model



In particular, the production level of firm *i* at time *t*, $i \in I = \{1, \dots, n_t\}$, is given by:

$$q_{it} = q_{i(t-1)}\left(1 + g_{it}^{q}\right), \tag{1}$$

where g_{it}^{q} is a modified version of the 'replicator dynamic' proposed by Metcalfe (1998: ch. 2), defined as (assuming a zero growth rate for the entire market demand):[5]

$$g_{it}^{q} = \delta\left(1 - \frac{c_{it}}{\bar{c}_{(t-1)}}\right), \tag{2}$$

where c_{it} denotes the production cost per unit of output of firm *i* at time *t*, $\bar{c}_t$ is the average of the firms' unit costs weighted by the corresponding market share s_{it} ($\bar{c}_t = \sum_{i=1}^{n_t} s_{it} c_{it}$ and $s_{it} = q_{it} / Q_t^S$). δ is the intensity of the selection mechanism. Clearly, given equation (1), we have $g_{it}^{q} \geq -1$, with $g_{it}^{q} = -1$ being equivalent to closure. In turn, the higher is δ, the stronger is the adjustment mechanism. We allow δ being firm- or industry-specific on the one hand, and constant or time-variant on the other. Within this context, a firm's growth rate is higher (lower) than the market average if its unit cost is lower (higher) than the average cost of the established firms.

In each period, firm *i* is characterised by the production function:[6]

$$q_{it} = \min\left(a_{it}^{1} x_{it}^{1}, \dots, a_{it}^{m} x_{it}^{m}\right) u_{it}, \tag{3}$$

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[5] The replicator dynamic equation was originally introduced into mathematical biology by R.A. Fisher. It was Silverberg (1987) who extended it to competition among firms. Silveberg's replicator equation relates each firm's market share to the difference between its competitiveness and the industry's average competitiveness (see also Silverberg, 1988). In the Metcalfe model, the growth rate depends on the absolute difference between individual unit costs and the corresponding industry average.

[6] For simplicity, our implementation assumes just two inputs. We note that the Nelson and Winter model (1982: ch. 12) assumes Leontief technologies, with each firm *i* at time *t* using the inputs in a given proportion. Since the Leontief technology forces the same complementary across inputs, the cost of variable inputs is constant across firms and over time. The techniques in the Nelson and Winter model are thus characterised by Hicks' neutral technical changes, with technical progress leading to proportional reductions in all inputs. In our case, although we assume a Leontief technology, we will allow for differences in productivity changes across inputs.

where q_{it} is firm's output at time *t*, x_{it}^{j} is firm's demand of the *j*th input, a_{it}^{j} ($a_{it}^{j} > 0$) is the productivity of input *j* (i.e. the amount of output produced per unit of input *j* under maximum efficiency), and u_{it} is an index of firm's production competence in the use of its technique, given by firm's productive efficiency level at time *t* (i.e. $u_{it} = q_{it} / q^{Max}$, where q^{Max} represents the best-practice of firm's technique; $0 < u_{it} \leq 1$).

The corresponding amount of inputs is given by:

$$x_{it}^{j} = \frac{1}{u_{it}} \frac{q_{it}}{a_{it}^{j}}, \tag{4}$$

and the unit production cost of this technology is given by:

$$c_{it} = \frac{1}{u_{it}} \left(\sum_{j=1}^{m} \frac{w^{j}}{a_{it}^{j}} \right), \tag{5}$$

where w^j is the price of the *j*th input.

In this framework, a change in firm's unit cost arises from technical progress (i.e. changes in parameters a_{it}^{j}) and from improvement of efficiency (i.e. changes in parameter u_{it}). When either a_{it}^{j} or u_{it} increase (decrease), the unit cost decreases (increases), as $\partial c_{it} / \partial a_{it}^{j} = -w^{j} (u_{it})^{-1} (a_{it}^{j})^{2} < 0$ and $\partial c_{it} / \partial u_{it} = -(u_{it})^{-2} \sum_{j=1}^{m} w^{j} (a_{it}^{j})^{-1} < 0$.

Industry output at time *t* is given by the sum of the firms' output levels:

$$Q_{t}^{S} = \sum_{i=1}^{n_t} q_{it} . \tag{6}$$

We assume that the industry faces a decreasing continuous (inverse) demand function:

$$P_t = D(Q_t^D), \tag{7}$$

where P_t is the market price and Q_t^D denotes the market demand at time *t*, with $\lim_{Q_t^D \to 0} D(Q_t^D) < \infty$ and $\lim_{Q_t^D \to \infty} D(Q_t^D) = 0$. In each period, equilibrium in the product market determines the market price at time *t*, that is, $P_t = D(Q_t^S)$.

The profit of firm *i* at time *t* is equal to total sales minus production and R&D costs:

$$\pi_{it} = \left[(1 - r_{it}) P_t - c_{it} \right] q_{it}, \tag{8}$$

where r_{it} is the R&D expenditure rate per unit of sales ($0 \le r_{it} < 1$).

3.2. The learning process

Learning and adapting over time is a key aspect to survivability, but routines are usually hard to change, and are responsible for inflexibility and inertia in organisational behaviour. Routines do change, however, as new knowledge is incorporated within the transmission of firm's knowledge over time (Metcalfe 1998).

Firms can learn through a diversity of sources of knowledge. Following Malerba (1992), we assume different types of firm's learning: 'learning by doing' and 'by using' (i.e. learning that emerges from production activity and from the use of products, machinery, and inputs), 'learning from advances in science and technology' and 'from inter-industry spillovers' (i.e. learning resulting from the exploitation of external sources of knowledge), and 'learning by searching' (i.e. learning that is related to research made within the firm). In our model firms can improve their productivity level via any of these three channels in the way described below.

Furthermore, it is assumed that improvements in the technological level are always achieved through learning (*disembodied* change), and not by investments in new, more productive equipment (*embodied* change). In other words, an improvement in technology always corresponds to a better knowledge of the production process, not to a replacement of the capital stock.[7]

Efficiency gains in the use of production technology result in our model from 'learning by doing' and from 'learning by using'. It is a continuous and cumulative process rather than the result of any deliberate R&D activity. We consider however that these two types of learning are conditioned in the following way: (i) the learning process is limited by the maximum efficiency of the technique used (i.e. the best-practice); and (ii) when a new technology is introduced the previous

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[7] For a model with vintage capital, see, for example, Silverberg et al. (1988). In our case, we assume that the capital stock is fully transferable from one technology to another.

productive knowledge is partly discarded (the technology-specific knowledge component). Thus, u_{it} can be written as:

$$u_{it} = 1 - e^{-v_{ik}\tau_{ik}} , \qquad (9)$$

where τ_{ik} is the number of periods during which firm i uses the technology k, and v_{ik} is a firm-specific parameter that denotes the learning speed. A smaller value of v_{ik} implies a slower learning process.

Before describing the changes in production parameters a_{it}^{j}, which, by assumption are obtained via innovation or imitation, we need to characterize two main alternative *technological regimes*. Indeed, we consider the concept of 'technological regime', introduced by Nelson and Winter (1977), as the key tool to understanding innovative activity. Two kinds of Schumpeterian regimes are thus distinguished. The entrepreneurial regime – a 'science-based' technology regime relatively favourable to new and innovative firms – and the routinized regime – a 'cumulative' technological regime that facilitates innovation from (large) established firms (Nelson and Winter 1982; Winter 1984).[8] In the entrepreneurial regime, the improvements in the current state of technological knowledge are mainly due to the new firms, while in the routinized regime such improvements are mostly associated to the established ones. In a 'science-based' technology, firms accumulate their own technological knowledge base from sources of knowledge external to the firm (for example, from public research institutions and from industry spillovers), and therefore technology is characterised by a broad and universal knowledge base. In a 'cumulative' technological regime, however, the sources of knowledge are internal to the firm and as a consequence the barriers to entry tend to be substantially higher.

In the routinized regime, it is assumed that more productive technologies are obtained, either by innovating new production processes or by mimicking the ones pre-existing within the

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[8] These two regimes are often referred to as 'Schumpeter Mark I' and 'Schumpeter Mark II' (Malerba and Orsenigo, 1995), by analogy with Schumpeter's conceptions of the innovative firms developed in *The Theory of Economic Development* (1934) and in *Capitalism, Socialism and Democracy* (1942).

industry. Following again the taxonomy introduced by Malerba (1992), in the former case, established firms adopt a 'learning by searching' process which is internal to the firm and mainly related to R&D activities; in the latter, firms adopt a 'learning from inter-industry spillovers' process, which is external to the firm and related to current industry knowledge. The capacity of a firm to absorb external knowledge also depends on its R&D activities ('absorptive capacity of firms', after Cohen and Levinthal, 1989; 1990).

We assume R&D investments are an increasing function of sales, and they can be either innovative (R_{it}^{N}) or imitative (R_{it}^{M}), as follows:

$$R_{it}^{N} = \alpha_i \, r_{it} \, P_t \, q_{it} , \tag{10}$$

$$R_{it}^{M} = \left(1-\alpha_i\right) r_{it} \, P_t \, q_{it} , \tag{11}$$

where α_i is a firm-specific parameter denoting the share allocated to innovation, $0 \leq \alpha_i \leq 1$ (if α_i is near to 1, the firm is a strong innovator), and r_{it} is the R&D expenditure rate.

Innovative and imitative knowledge are then accumulated as follows:

$$Z_{it}^{N} = \theta_i^{N} Z_{i(t-1)}^{N} + \left(1-\theta_i^{N}\right) R_{it}^{N} , \tag{12}$$

$$Z_{it}^{M} = \theta_i^{M} Z_{i(t-1)}^{M} + \left(1-\theta_i^{M}\right) R_{it}^{M} , \tag{13}$$

where Z_{it}^{N} and Z_{it}^{M} are the innovative and imitative stock of knowledge of firm *i* at time *t*, respectively, and θ_i^{N} and θ_i^{M} are firm-specific parameters weighting past research ($0 < \theta_i^{N} < 1$ and $0 < \theta_i^{M} < 1$).

The quality (i.e. the probability of success) of R&D activities depends on both past and current R&D investment. We have modelled technological change as a three-stage process. The first stage determines whether a firm's R&D activities result in innovation or imitation in the current period. This is established by random variables d_N and d_M (the subscripts *N* and *M* denote innovation and imitation, respectively) which is equal to one (success) or zero (failure). A firm's probability of success in innovation/imitation is an exponential function of the stock of knowledge:

$$\Pr\left(d_N = 1\right) = 1 - e^{-b_N Z_{it}^N}, \tag{14}$$

$$\Pr\left(d_M = 1\right) = 1 - e^{-b_M Z_{it}^M}, \tag{15}$$

where b_N and b_M are industry-specific exogenous parameters of technological opportunities for innovative and imitative success, respectively.

We assume that innovative draws are based on the current input productivity level which means that each firm follows its own technological path. Thus, in the second stage, if a firm is successful in innovating ($d_N = 1$), the resulting input productivities are determined by a log normal distribution with a log mean $\mu_{it}^j = \ln\left[\left(1 + g_{it}^j\right) a_{it}^j\right]$ and standard deviation σ. That is:

$$\ln a_{it}^{jN} \sim N\left(\mu_{it}^j, \sigma^2\right), \tag{16}$$

where g_{it}^j ($g_{it}^j > 0$) is the rate of productivity growth associated with innovation and it is stochastically determined.

A successful imitation ($d_M = 1$) means that the firm learns about a subset of past production techniques available in the industry and is able to converge to the best practice. Formally, the firm chooses the technique with the lowest unit production cost:

$$\tilde{c}_t^M = \min\left(\ldots; \tilde{c}_{(h-l)(t-1)}; \ldots; \tilde{c}_{h(t-1)}; \ldots; \tilde{c}_{(h+l)(t-1)}; \ldots\right), \tag{17}$$

where $\tilde{c}_{ht} = \sum_{j=1}^m w^j / a_{ht}^j$, $h \in I$. In this case, firms follow the path of the most efficient competitor (with one lag).

Finally, the firm has to choose, for the next period, between $\tilde{c}_{it}^N$, $\tilde{c}_t^M$ and the current technique, $\tilde{c}_{it}$, given by:

$$\tilde{c}_{i(t+1)} = \min\left(\tilde{c}_{it}; \tilde{c}_{it}^N; \tilde{c}_t^M\right), \tag{18}$$

where $\tilde{c}_{it}^N = \sum_{j=1}^m w^j / a_{it}^{jN}$. The firm then defines the new vector of input productivities $\left(a_{i(t+1)}^1; \ldots; a_{i(t+1)}^j; \ldots; a_{i(t+1)}^m\right)$ for the next period.

In the entrepreneurial regime, it is assumed that more productive technologies are obtained from an innovation process that depends mostly on external sources of knowledge. Since, by definition, firms learn from external 'advances in science and technology', the technology is mostly non-cumulative. But it is assumed that the capacity of a firm to absorb external knowledge depends on the level of the R&D effort (Cohen and Levinthal, 1989; 1990).

As in the routinized regime, we have modelled the innovation process as a three-stage process. In the first stage, it is determined whether firm's R&D activities result in innovation; the second stage gives the change in input productivity; finally, the firm chooses between the old and new technique (thus, we recover equations (10) to (18), with $\alpha_i = 1$ to preclude the possibility of imitation). If a firm is successful in innovating ($d_N = 1$), the technique upgrade is then given by a log normal distribution, but centred around the industry's average productivity in the period t-1, that is, $\mu_{it}^{j} = \ln\left[\left(1+g_{it}^{j}\right)\bar{a}_{i(t-1)}^{j}\right]$, where $\bar{a}_{t}^{j} = \sum_{i=1}^{n_t} s_{it} a_{it}^{j}$ is the average industry input productivity weighted by the corresponding market shares. The assumption that innovative draws are based on average industry input productivity levels translates the idea that the innovative process is largely non-cumulative, with all firms following more or less directly the industry technological path.

3.3. *R&D effort for the next period*

Having selected the technique to use in the next period**,** firms have then to decide on the R&D investment for the next period. This is modelled in two stages. As a first step, firms determine whether they want to adjust its level of R&D investment towards the industry average. This decision is made by comparing the performance (i.e. the net present value) of each firm and the industry average. A firm will decide to increment the R&D expenditures if its net present value is lower than the industry average, that is, if $V_{it} > V_t$. The net present value of an established firm with an infinite horizon and a constant discount rate (v), is given by:

$$V_{it} = \pi_{it} + \sum_{\tau=t+1}^{\infty} \left(1+\nu\right)^{-\tau} E(\pi_{i\tau}), \qquad (19)$$

where $E(\pi_{i\tau})$ is the expected profit in period *t*. $E(\pi_{i\tau}) = \left(1+\hat{g}_{it}^{\pi}\right)\hat{\pi}_{it}$, where $\hat{\pi}_{it} = \rho\ \hat{\pi}_{i(t-1)} + \left(1-\rho\right)\ \pi_{it}$ and $\hat{g}_{it}^{\pi}$ is the average profit growth rate given by $\hat{g}_{it}^{\pi} = \varphi\ \hat{g}_{i(t-1)}^{\pi} + \left(1-\varphi\right) g_{it}^{\pi}$, if $\hat{g}_{it}^{\pi} > 0$, or $\hat{g}_{it}^{\pi} = 0$ otherwise. φ and ρ are weighting parameters, with $\varphi, \rho \in]0,1[$.

Equation (19) can then be written:

$$\begin{cases} V_{it} = \pi_{it} + \dfrac{\hat{\pi}_{it}}{v - \hat{g}_{it}^{\pi}}, & \text{for } \hat{g}_{it}^{\pi} < v, \\ V_{it} = +\infty, & \text{for } \hat{g}_{it}^{\pi} \geq v \text{ and } \hat{\pi}_{it} > 0, \\ V_{it} = -\infty, & \text{for } \hat{g}_{it}^{\pi} \geq v \text{ and } \hat{\pi}_{it} < 0, \\ V_{it} = \pi_{it}, & \text{for } \hat{\pi}_{it} = 0. \end{cases} \tag{20}$$

The average net present value of the industry is given by:

$$\overline{V}_t = \sum\nolimits_{\tau=t}^{\infty} \left(1+v\right)^{-\tau} E(\pi_\tau); \tag{21}$$

or, assuming $E(\pi_\tau) = \hat{\pi}_t$:

$$\overline{V}_t = \hat{\pi}_t \left(1 + \frac{1}{v}\right), \tag{22}$$

with $\hat{\pi}_t = \psi\ \hat{\pi}_{(t-1)} + \left(1-\psi\right)\ \overline{\pi}_{t-1}$. ψ is the weighting parameter ($0 < \psi < 1$) and $\overline{\pi}_t = \sum\nolimits_{i=1}^{n_t} s_{it}\pi_{it}$. Thus, the desired R&D investment rate for the next period, $r_{i(t+1)}^{des}$, is determined according to the following rule:

$$\begin{cases} \text{If } V_{it} \geq \overline{V}_t,\ r_{i(t+1)}^{des} = r_{it}, \\ \text{If } V_{it} < \overline{V}_t,\ r_{i(t+1)}^{des} = (1-\beta_i)r_{it} + \beta_i \overline{r}_{(t-1)} + \omega_{it}, \end{cases} \tag{23}$$

where $\overline{r}_{(t-1)}$ is the weighted average R&D expenditure rate in period *t*-1 ($\overline{r}_t = \sum\nolimits_{i=1}^{n_t} s_{it} r_{it}$), β_i is the firm-specific parameter that gives the rate of adjustment ($0 < \beta_i < 1$), and ω_{it} is a random variable. According to this rule, if a firm's performance is not satisfactory (i.e. if it is lower than industry average), the R&D effort will increase in the direction of the industry R&D average.

Finally, the R&D expenditure rate to be implemented by the firm in the following periods is determined. It is assumed that the rate of R&D investment is bounded from above by the unit profit before non-production costs, such that the R&D expenditure rate in the next period is given by:

$$r_{i(t+1)} = \min\left[r_{i(t+1)}^{des}, \max\left(1 - \frac{c_{it}}{P_t}, 0\right)\right]. \tag{24}$$

3.4. Entry and Exit

Firms decide whether to continue or to exit and potential entrants decide whether to enter or not. We assume that entry and exit barriers are connected to the structural characteristics of the industry, given by entry and exit costs, *E* and *X*, respectively. (These costs, however, are never set to preclude entry or exit of firms.) The entry barriers are determined by the nature of the knowledge base and by the properties of the learning processes (Marsili 2001). Exit barriers influence the behaviour of firms by imposing non-transferability of specific assets, such as specific skills and accumulated knowledge (Caves and Porter 1976).

The exit decision is taken in period *t,* and it is implemented at the beginning of period *t*+1. A firm will decide to stay in the industry if $V_{it} \geq V_{it}^{X}$, that is, if the corresponding net present value is higher than the alternative (exit). V_{it}^{X} is the net present value of an established firm that decides to exit and it is given by:

$$V_{it}^{X} = \pi_{it} - X\ . \tag{25}$$

Considering (19) and (25), a firm decides to stay if positive profits are expected or if the absolute value of expected losses is lower than the exit cost, yielding the following rule:

$$\begin{cases} \text{Stay, if } E(\pi_{it}) > 0 \\ \text{Stay, if } E(\pi_{it}) < 0 \text{ and } \left|\sum_{\tau=t+1}^{+\infty}(1+\nu)^{-\tau} E(\pi_{it})\right| \leq X \\ \text{Exit, otherwise.} \end{cases} \tag{26}$$

Or, using the condition established in (20):

$$\begin{cases} \text{Exit, if } \hat{\pi}_{it} < 0 \text{ and } \hat{g}_{it}^{\pi} \geq \nu \\ \text{Exit, if } \hat{\pi}_{it} < 0 \text{ and } \hat{g}_{it}^{\pi} < \nu \text{ and } \left|\hat{\pi}_{it}\right| \geq \left(\nu - \hat{g}_{it}^{\pi}\right) X \\ \text{Stay, otherwise.} \end{cases} \tag{27}$$

The number of entrants can be defined in several ways. For example, Llerena and Oltra

(2002), Bottazzi, Dosi and Rocchetti (2001) and Winter (1984) define the number of potential entrants as a stochastic Poisson process to then evaluate whether potential entrants become actual entrants, while Marsili (2001) defines the number of entrants exogenously, using a constant entry rate with a stochastic disturbance. Our implementation is similar to the latter. Thus, we define the number of new firms as follows:

$$m_t = \gamma_t \; n_{t-1}, \tag{28}$$

where m_t is the number of entrants in period t (approximated at the nearest integer), γ_t ($\gamma_t > 0$) is the entry rate and n_{t-1} is the number of established firms in the period $t-1$. The entry rate is given by a normal distribution $\gamma_t \sim N\left(\mu_E, \sigma_E^2\right)$, with $\mu_E = f(E)$ and $f' < 0$ (i.e. γ_t is decreasing with the level of entry barriers).

The entry decision is taken in period t and becomes effective at the beginning of period t+1. Only established firms are able to improve the current state of technology in the routinized regime, while only new firms can do so in the entrepreneurial regime. The productivity level of inputs of new firms are thus drawn from a log normal distribution centred on the log of industry average productivity (i.e. $\mu_{et}^j = \ln \bar{a}_{t-1}^j$) in the routinized regime, and on the log of best practice observed in the industry (i.e. $\mu_{et}^j = \ln\left[\left(1+g_{et}^j\right) \tilde{a}_{t-1}^{jM}\right]$) in the entrepreneurial regime ($\tilde{a}_t^{jM}$ is given by equation (17) above; subscript e denotes potential entrant).

Whether a *potential entrant* becomes an actual *entrant* depends on the evaluation of the profit opportunities generated by its technology at the time of entry. The potential entrants can be mistaken about the evaluation of the profit opportunity via, namely, a bad judgement of the potential productivity level of the technique. The net present value of a potential entrant is given by:

$$V_{et}^E = \sum\nolimits_{\tau=t+1}^{\infty} \left(1+\nu\right)^{-\tau} E(\pi_{i\tau}) - E\,. \tag{29}$$

A potential entrant decides to enter the industry if the (discounted) expected profits are higher than the entry cost, that is, if

$$E(\pi_{et}) > \nu E\,. \tag{30}$$

The production technique is defined at the outset in case of entry. The full specification of the initial characteristics of each firm is therefore required. We assume, in particular, that the entry scale is small relative to the size of the market and determined by a normal distribution $q_{et} \sim N\left(\mu_q, \sigma_q^2\right)$, with $\mu_q < \overline{q}_t$. Whether the R&D effort is innovative or imitative is randomly determined. The remaining parameters are similar to those for the established firms.

4. Simulation results: the impact of entry and exit on industry productivity growth

Our numerical simulation is implemented by using the *Laboratory for Simulation Development* (Lsd) software.[9] The main purpose is to evaluate to what extent the model is able to replicate some of the stylized empirical regularities on firm dynamics reported in Section 2 above. We also want to analyse the specific contribution of market share reallocation to aggregate productivity growth.

In each technological regime, we consider five separate entry/exit scenarios of 200 consecutive production periods (quarters). To test for the robustness of our findings with respect to model parameterization (the model assumes a considerable number of random parameters), each scenario is replicated 100 times, making a total of 100x200 runs per scenario. Either the number of production periods or the number of replications could be easily extended, but no substantial gain would be obtained. We believe indeed to have generated enough and representative statistics that allows us to establish our findings with a comfortable degree of confidence.

To begin with, we have the no entry/no exit case as a benchmark implementation. Then, using the entry rates reported in Dunne, Roberts and Samuelson (1988) and Audretsch and Acs (1994), we calibrate the mean of the random entry rate (i.e. μ_E of γ_t) to 1.050, 1.075, 1.100, 1.125 and 1.150% per quarter in the corresponding five routinized regime cases, and 3.800, 3.825, 3.850,

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[9] Lsd is a simulation package developed by Marco Valente for IIASA (Austria) and for IKE/DRUID (Aalborg University, Denmark). See Valente and Andersen (2002). The software is available for free downloading at http://www.business.aau.dk/~mv/Lsd/lsd.html.

3.875 and 3.900% per quarter in the other five entrepreneurial regime cases. The parameter defining exit barriers is assumed to be equal to 2 in the routinized regime (high barriers) and 0 in the entrepreneurial regime (low barriers).

All other industry and firm parameters are identical across implementations. In particular, our exercise considers an initial population of 65 heterogeneous/single-output/single establishment firms with distinct R&D intensity and productivity levels. To simplify, the production technology uses only two inputs, with the initial productivity level of input 1 ranging from 0.868 to 1.101, and from 1.536 to 1.745 in the case of input 2. The corresponding averages are equal to 0.999 and 1.643. The initial R&D rate per unit of sales ranges between 0.5 and 9.0%, with an average equal to 4.77%. The average initial market share is identical for all firms and equal to 0.0154 (or 1/65). As in the Nelson-Winter model, we assumed a 'mature' market with a unit elastic (inverse) demand given by $P_t = 65/Q_t$. The values of parameters are presented in Appendixes A and B.

4.1. Analysing the evolution of industry

So how does the model fare in terms of its ability to replicate the empirical regularities on firm dynamics documented in Section 2? Table 1 shows the selected industry statistics generated by each industry configuration. Clearly, the final number of firms is (11 to 15 percent) higher in the entrepreneurial regime than in the routinized regime, either in terms of the average over the entire production cycle (200 periods) or at the final period (i.e. at *t=200*). The Herfindahl equivalent number of firms index shows in turn that market concentration is higher in the routinesed regime than in the entrepreneurial regime. At *t=200*, for example, there are between 113.7 and 114.4 'equivalent' firms in the routinized regime, and 119.7 to 138.9 in the entrepreneurial regime. The corresponding standard deviations are also considerably higher in the latter.

Table 1: Selected industry statistics

	No entry-No exit	Routinized regime					Entrepreneurial regime				
		Entry parameters									
		0.01050	0.01075	0.01100	0.01125	0.01150	0.03800	0.03825	0.03850	0.03875	0.03900
Average over 200 periods											
Number of firms	65.00	111.42	111.45	111.43	111.46	111.48	127.35	123.74	126.15	128.32	126.16
		(9.098)	(9.125)	(9.136)	(9.188)	(9.165)	(30.461)	(23.469)	(28.159)	(48.271)	(29.926)
Herfindahl index (inverse)	55.65	105.79	105.84	105.80	105.82	105.82	120.39	117.60	119.84	121.48	119.99
	(3.329)	(7.425)	(7.472)	(7.461)	(7.496)	(7.495)	(24.116)	(19.755)	(25.068)	(45.146)	(26.163)
Hymer-Pashingian index	0.008	0.024	0.024	0.024	0.024	0.024	0.031	0.031	0.032	0.032	0.032
	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)	(0.007)	(0.030)	(0.026)	(0.027)	(0.026)	(0.027)
Entry rate (per quarter)	--	0.018	0.018	0.018	0.019	0.019	0.046	0.047	0.047	0.047	0.047
		(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.007)	(0.007)	(0.009)	(0.007)	(0.005)
Exit rate (per quarter)	--	0.007	0.007	0.007	0.007	0.008	0.035	0.036	0.036	0.036	0.036
		(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.042)	(0.040)	(0.039)	(0.040)	(0.041)
Final period (t = 200)											
Number of firms	65.00	123.57	123.18	123.54	123.68	123.39	147.47	135.76	144.15	163.03	143.84
		(3.723)	(3.888)	(4.580)	(4.895)	(4.880)	(61.691)	(35.395)	(41.729)	(108.632)	(55.700)
Herfindahl index (inverse)	51.84	114.39	114.02	114.13	114.15	113.74	126.46	119.65	122.32	138.85	124.45
	(1.79)	(3.749)	(3.525)	(4.148)	(4.354)	(4.755)	(40.064)	(32.587)	(32.517)	(101.369)	(34.251)
Hymer-Pashingian index	0.005	0.022	0.022	0.022	0.022	0.023	0.036	0.042	0.030	0.032	0.035
	(0.003)	(0.007)	(0.006)	(0.007)	(0.007)	(0.007)	(0.062)	(0.088)	(0.017)	(0.049)	(0.053)
Entry rate (per quarter)	--	0.017	0.017	0.017	0.018	0.018	0.046	0.046	0.046	0.047	0.047
		(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.008)	(0.008)	(0.009)	(0.007)	(0.005)
Exit rate (per quarter)	--	0.008	0.008	0.008	0.008	0.009	0.040	0.035	0.029	0.038	0.042
		(0.007)	(0.007)	(0.008)	(0.008)	(0.008)	(0.083)	(0.075)	(0.021)	(0.070)	(0.072)

Notes: Average over 100 simulation runs for each industry configuration. Standard deviations are in parenthesis.

Comparing with no entry/no exit scenario, all 10 selected scenarios generate larger rates of turbulence. As shown by the Hymer-Pashingian index (line 3, panels *a)* and *b*), columns 3 and 8), 3.2% of the total market share, on average, are transferred across firms in the entrepreneurial regime, while in the routinized regime this figure is only 2.4%.[10] In the no entry/no exit scenario, this reallocation rate does not exceed 0.8%. There is, therefore, one third more turbulence in the entrepreneurial regime than in the routinized regime, a pattern very close to the one found by Audretsch and Acs (1990).

Much of the market turbulence is of course linked to the entry and exit of firms. As Table 2 shows, the annual entry and exit rates are quite distinct in the two technological regimes.[11] For example, the entrepreneurial regime yields an annual entry rate of 13.5% and an exit rate of 12.0% (averages over the 200 periods), while for the routinized regime the corresponding entry and exit rates are 2.9% and 1.8%. This finding confirms some stylised facts, according to which many industries, especially those closer to the routinized regime, show average annual entry rates lower than 3%, while other industries, closer to the entrepreneurial regime, exhibit entry rates higher than 12% (Dunne, Roberts and Samuelson, 1988; Geroski, 1991; Baldwin, 1995).

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[10] The Hymer-Pashingian instability index, I_t, is an indicator of market turbulence, and it is computed as the sum of one-period variations in absolute value in firms' market shares: $I_t = \sum_{i=1}^{n_t} \left| s_{it} - s_{i(t-1)} \right|$ or $I_t = \sum_{c=1}^{c_t} \left| s_{ct} - s_{c(t-1)} \right| + \sum_{e=1}^{e_t} s_{et} - \sum_{x=1}^{x_t} s_{x(t-1)}$, where c denotes continuing firms, e new firms, and x exiting firms.

[11] Entry and exit rates are computed using the method suggested by Dunne, Roberts and Samuelson (1988).

Table 2: Annual entry and exit rates

	Routinized regime					Entrepreneurial regime				
	Entry parameters									
	0.01050	0.01075	0.01100	0.01125	0.01150	0.03800	0.03825	0.03850	0.03875	0.03900
Average over 50 years										
Entry rate	0.0288	0.0290	0.0294	0.0298	0.0303	0.1340	0.1339	0.1353	0.1360	0.1369
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.020)	(0.019)	(0.024)	(0.019)	(0.017)
Exit rate	0.0173	0.0176	0.0179	0.0182	0.0188	0.1174	0.1199	0.1200	0.1197	0.1216
	(0.014)	(0.014)	(0.014)	(0.014)	(0.015)	(0.072)	(0.066)	(0.066)	(0.066)	(0.068)
Final period										
Entry rate	0.0233	0.0236	0.0259	0.0274	0.0288	0.1341	0.1343	0.1367	0.1388	0.1396
	(0.007)	(0.008)	(0.010)	(0.009)	(0.010)	(0.028)	(0.024)	(0.028)	(0.024)	(0.023)
Exit rate	0.0202	0.0203	0.0205	0.0231	0.0258	0.1270	0.1270	0.1324	0.1283	0.1238
	(0.012)	(0.014)	(0.014)	(0.014)	(0.016)	(0.160)	(0.119)	(0.133)	(0.121)	(0.130)

Notes: Averages over 100 simulation runs for each industry configuration. The rates are defined as the ratio of entrants (exiting firms) in *t* to the total number of firms in *t*-1. Standard deviations are in parenthesis.

Table 3: Survival rate of new firms (in percentage)

		Years after birth									
		1 year	2 years	3 years	4 years	5 years	6 years	7 years	8 years	9 years	10 years
Routinized regime											
Entry parameter	0.01050	86.4	83.1	80.1	77.1	74.1	71.4	68.6	65.8	63.3	60.7
	0.01075	86.7	83.4	80.2	77.2	74.2	71.4	68.6	65.7	63.1	60.5
	0.01100	86.5	83.1	80.0	76.8	73.9	70.8	68.1	65.1	62.5	59.9
	0.01125	86.3	82.8	79.4	76.2	73.3	70.4	67.7	64.9	62.3	59.7
	0.01150	86.4	82.8	79.3	76.0	72.8	70.0	67.3	64.3	61.7	59.1
Entrepreneurial regime											
Entry parameter	0.03800	83.5	70.6	59.6	50.5	43.1	36.7	31.5	27.1	23.4	20.4
	0.03825	83.5	70.5	59.5	50.3	42.8	36.4	31.3	26.9	23.3	20.2
	0.03850	83.0	70.2	59.4	50.2	42.6	36.2	31.0	26.7	23.0	19.9
	0.03875	83.4	70.4	59.2	50.0	42.3	36.1	30.8	26.5	22.9	19.8
	0.03900	83.5	70.3	59.2	49.8	42.2	35.7	30.5	26.2	22.5	19.4

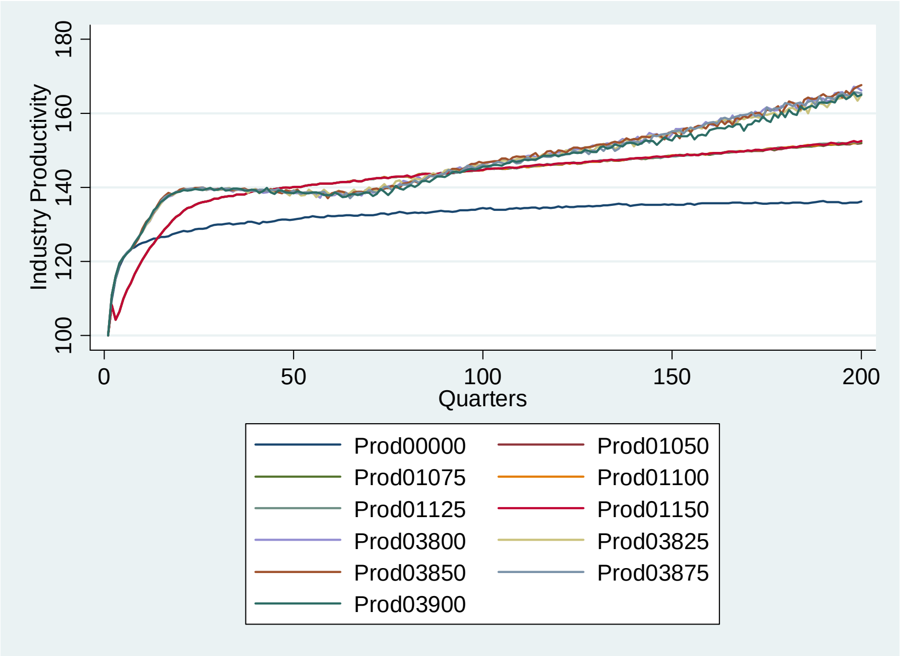
Notes: Averages over 100 simulation runs for each industry configuration. The survival rate is defined as the number of new firms surviving in a given year after birth, as a percentage of the total number of new firms.

Entry and exit are highly positively correlated. This correlation is determined, in the first instance, by the rate of early mortality of new firms, which is very high in both technological regimes. Table 3 provides the distribution of the number of production periods in which newly created firms operate before closing. Around 14% of new firms close within the first year (i.e. before four production periods) in the routinized regime, while in the entrepreneurial regime the corresponding figure is approximately 17%. Ten years after birth, 60% of entrants are still in operation in the routinized regime. The corresponding rate in the entrepreneurial regime is only 20%. This of course confirms the stylised fact that early mortality among entrants is particularly high in the entrepreneurial regime, as found by Geroski (1991), Audretsch (1991), Mata, Portugal and Guimarães (1995) and Baldwin (1995).

4.2. Firm dynamics and industry-level productivity growth

The next issue is whether all the generated firm mobility implies a higher aggregate productivity growth. Let us first compare the productivity growth across the two technological regimes. Figure 2 plots the evolution of aggregate productivity. (Individual productivity levels are weighted by the corresponding market shares.) Both technological regimes generate a higher Fisher index of productivity than in no entry/no exit scenario: the final period productivity index is, respectively, 152.5 and 167.6 in the routinized and entrepreneurial regimes, and only 136.3 in the case of no entry/no exit (base 100 at $t=0$). Converting into annual average growth rates, this is equivalent to 1.04, 0.85, and 0.62%, respectively.

Figure 2: Industry productivity

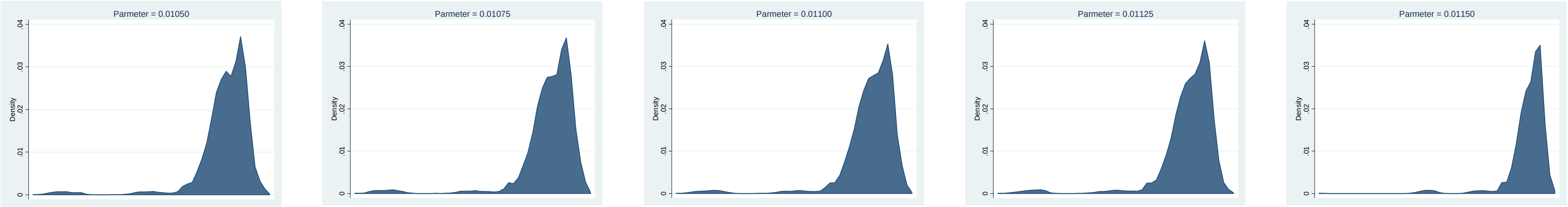


Notes: Base 100 at *t=0*. Prod00000-Prod03875 denote the industry productivity index associated with the corresponding mean of the random entry rate (see Appendix A).

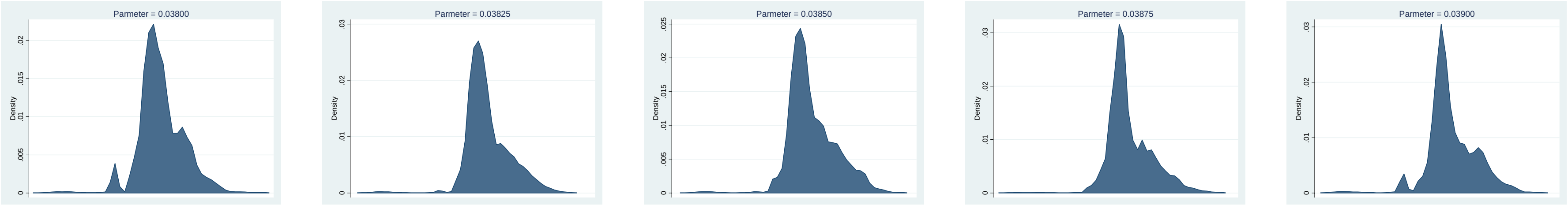
As Figure 3 and Table 4 show, the 'technological space' is exploited differently across the two types of technological regimes. In the first place, dispersion in productivity levels is higher in the entrepreneurial regime than in the routinezed regime. (The lowest dispersion is in the no entry/no exit scenario.) The productivity distribution is left-skewed in the case of routinized regime, with a long tail in the negative direction (i.e. the mean is lower than the median – the negative skewness is indeed between -3.48 and -3.26). In the entrepreneurial regime, in contrast, the distributions are weakly right-skewed. The maximum productivity level in the routinized regime is also much closer to the third quantile than in the entrepreneurial regime case. Thus, the more concentrated productivity distribution on top values in the former case does not result in a higher average productivity growth rate.

Figure 3*:* Distribution of the final period productivity of firms

Routinized regime



Entrepreneurial Regime



Note: Pooling of 100 simulations (final period).

Table 4: Distribution of the final period productivity of firms

	No entry- No exit	Routinized regime					Entrepreneurial regime				
		Entry parameters									
		0.01050	0.01075	0.01100	0.01125	0.01150	0.03800	0.03825	0.03850	0.03875	0.03900
Average	202.79	227.61	227.64	228.12	228.04	228.15	242.58	241.20	244.09	239.94	240.42
Standard deviation	15.95	19.70	19.93	19.52	19.83	19.86	26.09	23.35	25.25	23.91	25.96
Minimum	80.96	96.15	96.52	95.66	96.74	98.46	98.82	105.54	107.32	103.66	104.40
First quantile	204.98	221.99	221.97	222.07	222.07	222.17	227.59	226.54	227.29	225.58	227.02
Median	206.84	230.93	231.18	231.50	231.73	232.33	238.97	235.80	237.80	233.02	234.73
Third quantile	207.88	238.87	238.91	239.93	239.71	239.68	257.32	253.50	258.26	252.55	254.92
Maximum	211.97	257.12	254.07	255.20	257.69	255.11	363.53	332.92	341.60	339.05	340.01

Note: Pooling of 100 simulations (final period).

Table 5: Net market share transferred from closings and contractions to openings and expansions, over 5-year period (in percentage)

	No entry- No exit	Routinized regime					Entrepreneurial regime				
		Entry parameters									
		0.01050	0.01075	0.01100	0.01125	0.01150	0.03800	0.03825	0.03850	0.03875	0.03900
Average of 5-year periods	4.91 (1.20)	12.49 (2.03)	12.63 (2.05)	12.80 (2.04)	12.98 (2.04)	13.28 (2.08)	50.71 (6.12)	51.02 (5.93)	51.15 (6.43)	51.21 (6.08)	52.15 (6.31)

Notes: Averages over nine 5-year periods. The corresponding values by period are available upon request (Appendix Table 5A). Standard deviations are in parenthesis.

Successful firms exclude unsuccessful ones and the result is a considerable resource reallocation and, hopefully, increased aggregate productivity growth. As Table 5 shows, the market share transferred from exiting and contracting units to entering and expanding units, over a 5-year period, was 12 to 13% in the routinized regime. The corresponding rate in the entrepreneurial regime is an astonishing 51 to 52%, while in the no entry/no exit scenario, the market share reallocation is very small at 5%.

In order to disaggregate the contribution of firm dynamics to industry productivity growth, the population of firms in each 5-year period was divided into four groups: continuing firms with increasing market shares, continuing firms with decreasing market shares, exiting firms, and entering firms. In each group we then computed the proportion of firms with a productivity index higher than the average/median productivity of continuing firms. For completeness, the productivity of entering firms was also compared with the productivity of exiting firms. These statistics are presented in Tables 6 and 7. The reported values are the averages over a time-span of 9 consecutive 5-year periods (i.e. over a total of 180 runs in each replication).[12] Since we are mostly interested in long-run effects, the first 5-year period was dropped from the analysis.

Table 6 shows that entrants are at least as productive as continuing firms. In the routinized regime, 67 to 68% of entrants show a productivity-level above the (beginning-period) average of continuing firms (line 1, columns 1-5). In the case of the entrepreneurial regime, only roughly one half of entering firms are more productive than the continuing firms average (line 1, columns 6-10), but they are clearly more productive than the average of exiting firms (measured at the beginning-period) and the median of continuing firms (lines 2 and 3, columns 6-10).

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[12] The corresponding values by period are available on request (Appendix Tables 6A-E and 7A-H).

Table 6: Proportion of entrants (exits) with higher (lower) productivity than average/median productivity of continuing firms (in percentage)

	Routinized regime					Entrepreneurial regime				
	Entry parameters									
	0.01050	0.01075	0.01100	0.01125	0.01150	0.03800	0.03825	0.03850	0.03875	0.03900
New firms with a productivity index higher than:										
continuing firms' average	66.87	66.99	66.95	67.72	68.12	47.22	47.03	47.33	47.07	48.53
	(14.57)	(14.90)	(15.34)	(15.31)	(15.36)	(39.89)	(39.00)	(39.55)	(39.72)	(40.25)
continuing firms' median	40.70	41.02	41.13	42.32	43.34	60.87	58.58	59.41	61.09	62.89
	(21.31)	(21.60)	(21.27)	(21.41)	(21.18)	(37.54)	(37.90)	(37.80)	(37.56)	(37.09)
exiting firms' average	47.47	48.01	47.71	50.15	49.90	75.30	75.58	72.97	74.75	76.15
	(28.42)	(28.28)	(28.52)	(27.87)	(27.10)	(32.60)	(32.11)	(33.36)	(32.37)	(31.73)
Exiting firms with a productivity index lower than:										
continuing firms' average	67.91	67.45	68.39	67.97	68.75	92.93	93.12	93.01	93.12	93.22
	(18.69)	(18.81)	(18.07)	(18.30)	(18.07)	(5.11)	(4.90)	(5.24	5.06)	5.07)
continuing firms' median	74.96	74.98	74.98	74.95	75.69	93.12	93.28	93.26	93.25	93.44
	(17.09)	17.73)	(16.85)	(17.51)	(16.72)	(4.81)	(4.71)	(4.93)	(4.85)	(4.82)

Notes: Averages over nine 5-year periods. The group of entering (exiting) firms comprises all firms that enter (exit) in a given period. Simultaneous entry and exit within any period is precluded. The reported values are obtained by dividing the number of entrants (exits) with a higher (lower) productivity index than the corresponding average of continuing firms by the total number of observed entrants (exits). The productivity index of continuing firms is measured at the beginning-period in the case of new firms and at the ending-period in the case of exits. The corresponding values by period are available upon request (Appendix Tables 5A-E). Standard deviations are in parenthesis.

Table 7: Proportion of continuing firms with increasing (decreasing) market shares with higher (lower) productivity than average and median productivity of whole continuing firms group (in percentage)

	Routinized regime					Entrepreneurial regime				
	Entry parameters									
	0.01050	0.01075	0.01100	0.01125	0.01150	0.03800	0.03825	0.03850	0.03875	0.03900
Continuing firms with increasing market shares and productivity above:										
continuing firms' average at *t*-1	97.10	97.06	96.95	97.01	97.02	83.99	83.93	83.08	82.96	81.79
	(6.44)	(6.44)	(6.80)	(6.77)	(7.68)	(24.82)	(24.52)	(25.03)	(25.80)	(26.96)
continuing firms' average at *t*	87.60	87.82	87.64	87.99	88.37	85.03	84.71	83.24	83.03	83.29
	(13.22)	(13.18)	(13.30)	(13.08)	(13.23)	(21.48)	(21.73)	(22.92)	(23.57)	(23.59)
continuing firms' median at *t*-1	83.68	83.63	83.42	83.58	83.37	80.42	80.19	79.58	80.23	77.71
	(14.34)	(14.36)	(14.64)	(14.82)	(14.98)	(27.13)	(27.23)	(27.21)	(27.32)	(29.26)
continuing firms' median at *t*	60.41	60.32	59.94	59.92	59.93	76.30	76.27	76.20	76.00	73.77
	(18.38)	(18.51)	(18.85)	(19.05)	(18.75)	(27.95)	(28.16)	(28.01)	(27.99)	(29.43)
Continuing firms with decreasing market shares and productivity below:										
continuing firms' average at *t*-1	39.10	38.99	38.60	38.42	38.14	54.01	54.68	55.61	54.01	54.01
	(18.00)	(18.04)	(17.83)	(17.63)	(17.72)	(33.15)	(33.44)	(33.88)	(33.12)	(34.06)
continuing firms' average at *t*	52.89	52.82	52.47	52.38	52.36	68.26	68.73	69.50	68.88	67.56
	(14.31)	(14.30)	(14.18)	(14.25)	(14.35)	(24.01)	(24.48)	(24.13)	(23.99)	(25.11)
continuing firms' median at *t*-1	52.47	52.32	51.85	51.85	51.79	46.62	48.24	48.02	46.98	48.16
	(15.89)	(15.88)	(15.56)	(15.59)	(15.64)	(29.18)	(29.40)	(29.98)	(29.82)	(29.37)
continuing firms' median at *t*	59.45	59.35	58.94	58.98	58.96	60.77	62.91	62.82	60.98	61.69
	(11.13)	(11.09)	(10.87)	(11.00)	(10.86)	(24.77)	(24.18)	(24.56)	(25.62)	(24.57)

Notes: Averages over nine 5-year periods. The group of continuing firms comprises all firms that remain active over a given period. In this group, firms were divided into two categories: those with an increasing market share and those with a decreasing market share. The proportions reported in the table for each group are then obtained dividing the number of firms with a higher productivity level than the average of continuing firms by the total number of observed firms in the corresponding category. The corresponding values by period are available upon request (Appendix Tables 5A-E). Standard deviations are in parenthesis.

The exiting firms are also strongly concentrated in the less productive lot in both technological regimes. In the routinized regime, 67 to 69% of exiting firms have a productivity level below the (ending-period) average of continuing firms; approximately 75% are below the median. These proportions are larger in the entrepreneurial regime: approximately 93% in both cases. On the whole there is therefore no shadow of doubt that exits have been replaced by new and more productive firms, substantiating a significant and positive entry-exit effect on industry productivity growth, especially in the entrepreneurial regime case.

Table 7 looks at *continuing firms with increasing/decreasing market shares* in detail. At first sight it seems that most firms which are gaining market share are also more productive. In the routinized regime, for example, 83 to 84% of firms with increasing market shares belong to the (beginning-period) top 50 per cent most productive continuing firms (line 3, columns 1-5), while approximately 97% of those firms have a productivity level above the continuing firms average (lines 1, columns 1-5). The percentage is even higher in the entrepreneurial regime case, at 78 to 82% and 82 to 84%, respectively (lines 3 and 1, columns 5-10). Symmetrically, continuing firms with decreasing market shares are in general less productive. In the case of the routinized regime, for example, approximately 59% of firms that are losing market share are located in (ending-period) 50 per cent less productive segment, while in the entrepreneurial regime this proportion is 61 to 63%. It is therefore quite clear that resource reallocation among continuing firms plays a substantial role on aggregate productivity growth, especially in the routinized regime case.

On the whole, this decomposition of productivity growth shows that exits and contraction do occur among less productivity units, while entry and expansion are concentrated among more efficient units. It follows therefore that our modelling was quite effective in replicating some major stylized facts of industry dynamics, including a very strong impact of entry-exit mechanism on aggregate productivity growth.

5. Concluding remarks

This paper examines industry dynamics as a source of aggregate productivity growth in two alternative technological regimes. Our evolutionary approach assumes that individual firms learn about technology through a variety of sources, and that, as a consequence, productivity growth and market shares across firms can be quite distinct. Aggregate productivity growth in this framework is thus determined by the micro productivity patterns associated with different technological regimes, on the one hand, and the ease of entry/exit, on the other.

Our numerical simulations do replicate key empirical regularities already reported in literature. In particular, they show that firm mobility has a very strong impact on industry productivity growth: firms that gain market share are the ones among the most productive lot, while continuing firms with decreasing market shares are in the bottom half of the distribution in terms of efficiency; exiting firms also tend to be replaced by new and more productive firms. It is therefore very clear that firm dynamics do matter both in terms of micro and aggregate productivity growth.

We also confirmed that the entry-exit effect is more dominant in the entrepreneurial regime, while the impact of resource reallocation among continuing firms is larger in the routinized regime. Not surprisingly, given that in the former the competition between the innovative entrants and the established firms is more head-to-head, the industry-level productivity growth is higher than in the latter.

On the whole, our results suggest that micro analysis is the proper complement to aggregate industry studies, as it provides a considerable insight into the causes of productivity growth. As to the policy implications of our analysis are concerned, the lesson seems to be quite straightforward: it claims for the promotion of an institutional environment more favourable to resource reallocation through entry and exit of firms in order to achieve a higher rate of production efficiency.

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Appendix A. Industry parameter settings:

Parameter	Description	Technological regime	
		Routinized	Entrepreneurial
D	Demand coefficient	65	65
v	Discount rate	0.1	0.1
δ	Intensity of the selection mechanism	0.1	0.1
w^1 and w^2	Price of inputs	0.1 and 0.5	0.1 and 0.5
θ, ρ and φ	Parameters weighting past values	0.5	0.5
β	Adjustment rate of R&D	0.5	0.5
b_N	Technological opportunities to innovate	5.3	5.3
b_M	Technological opportunities to imitate	11.3	11.3
σ	S.D. of innovative draws	0.006	0.006
g^{max}	Maximum rate of innovative draws	0.01	0.01
μ_E	Mean of random entry rate	0.0105; 0.01075; 0.011; 0.01125; 0.0115	0.038; 0.03825; 0.0385; 0.03875; 0.039
σ_E	S.D. of random entry rate	0.001	0.004
X	Exit barrier	2	0

Appendix B. Firm parameters (for the two technological regimes):

Initial productivity of input 1: a^1 = {1.0991 0.929228 0.993226 0.999833 1.04484 0.945796 1.01556 1.02504 1.00675 0.973121 0.925113 1.01671 0.953578 0.985178 1.04245 0.934288 1.0473 0.966943 0.918181 1.00295 1.00663 1.06109 0.978114 0.868066 0.917641 0.999854 1.10119 1.03197 1.04458 0.977986 1.01237 0.996525 1.02672 1.01125 1.09296 1.03496 1.02052 1.05661 1.04263 1.04209 0.996295 0.928016 0.984648 0.972298 1.04867 1.04974 1.00187 0.882119 1.04836 0.986049 1.01821 1.00929 1.00738 0.959658 1.01327 1.0635 1.03081 1.02015 0.956651 0.905239 0.974466 0.955911 0.993446 0.980341 0.999548}

Initial productivity of input 2: a^2 = {1.6748 1.58718 1.67204 1.74477 1.64776 1.68122 1.6271 1.72348 1.67377 1.61058 1.69891 1.63541 1.67465 1.69544 1.62376 1.6837 1.6786 1.65646 1.62994 1.72163 1.67919 1.56711 1.53568 1.65505 1.57418 1.6539 1.58759 1.62937 1.6023 1.61133 1.72763 1.60602 1.6511 1.64455 1.63939 1.65958 1.68059 1.61299 1.6221 1.63791 1.67567 1.62071 1.64737 1.58857 1.60842 1.68473 1.56586 1.66965 1.70013 1.70271 1.62711 1.57017 1.61791 1.57716 1.68099 1.5866 1.60789 1.62867 1.74547 1.66272 1.72141 1.58121 1.64182 1.56648 1.59843}

Initial R&D expenditure rate per unit of sales: r = {0.0641965 0.0503617 0.0344462 0.0431363 0.0731603 0.0622908 0.0199951 0.0497315 0.0289174 0.0620039 0.0509556 0.0680779 0.0541377 0.0462283 0.047612 0.03144 0.025664 0.0562811 0.066097 0.033032 0.0362245 0.0269913 0.0579717 0.0510349 0.0255884 0.0558446 0.0643353 0.0378444 0.0309043 0.0412489 0.0425808 0.0657927 0.0669956 0.0555556 0.0196003 0.0818574 0.0145982 0.0457228 0.067336 0.0608757 0.00574432 0.0167786 0.0649273 0.0276446 0.0682775 0.0868907 0.0481435 0.0296261 0.0680171 0.0499932 0.0617636 0.0770782 0.0458726 0.0611841 0.037955 0.0629541 0.0617017 0.0428776 0.0672116 0.0234899 0.0164829 0.0150083 0.0399822 0.044859 0.0576941}

Initial share of R&D allocated to innovation: α = {0.27421 0.460697 0.783865 0.860226 0.983236 0.843975 0.582421 0.986503 0.75171 0.60564 0.117437 0.150394 0.944753 0.556836 0.0220837 0.642979 0.670098 0.917848 0.446023 0.707826 0.817101 0.266613 0.70695 0.584787 0.695679 0.544023 0.163081 0.528548 0.160749 0.626861 0.782992 0.436638 0.446866 0.00634169 0.903301 0.680562 0.746679 0.343818 0.460434 0.37191 0.52096 0.659053 0.00934752 0.686102 0.0706349 0.720768 0.103797 0.00425392 0.160274 0.70932 0.215826 0.588119 0.389731 0.246733 0.279293 0.0668498 0.297022 0.54171 0.385769 0.833682 0.518478 0.0552788 0.813266 0.542393 0.0574753}

Initial market share: s = {0.015385 0.015385}

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