Microeconomics of industry life cycles: a simulation based model of firm learning and organisational jumping.

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Abstract

This paper develops a simulation based model of industry life cycles. The analytical framework is grounded in a generalised Cournot model, but with a key development involving organisational effort, as well as physical output, as a choice variable. Effort is assumed to influence demand (positively) and average production costs (non-positively). Two profit maximising effort equilibria can exist, denoted small and large organisational size. This introduces the possibility that a firm can "jump", or undertake a developmental organisation leap from small to large solutions, to exploit demand and production cost advantages. Organisational jumping is analysed here in terms of a probability and a stochastic process. A small probability of jumping is viewed as knowledge of development possibilities being not generally diffused throughout the population of firms, a characteristic of an early (pre-shakeout) life cycle. A larger probability describes a more generalised diffusion of development possibilities, and so describes a post-shakeout life cycle. Simulation results are consistent with key features identified in the literature: high levels of entry and exit and survival uncertainty with no apparent steady state pre-shakeout; post-shakeout the development of a stable (steady state) oligopoly based on large firms. These results are derived with unchanged demand and cost functions and hence are driven by the probability of effort jumping. This analytical driver is interpreted as grounding the analysis in a Marshallian logic. The alternative Schumpeterian logic is precluded because of parameter stability.

Key words: industry life cycle; generalised Cournot model; organisational step change; simulation method.
JEL codes: D21, D23, D43, D83, L13.

Introduction

The main objective of this paper is to use a somewhat standard theoretical approach to the firm and industry, i.e. a generalised Cournot oligopoly, to generate results consistent with industry life-cycle (ILC) effects; and in particular an approach to ILCs that views learning as a key driver of industry evolution. The reason for the qualification "somewhat" standard is that the Cournot framework is developed beyond that commonly adopted to allow demand and unit production costs to be endogenous to what is called organisational effort. This addition to the standard theory allows us to generate the ILC effects that we find.

The basic structure of the argument can be presented as follows. The theoretical framework generates two classes of effort solutions: either a unique or two solutions. The latter possibility indicates that two types of firms can exist with "small" and "large" organisational size. This is the case even with the assumed symmetric firm revenue and cost functions. The difference between small and large organisations introduces the possibility of a developmental leap taking place in which firms can "jump" from small to large effort. In concrete terms a jump of this sort involves a major organisational investment with a step change in firm size. For the framework developed here, this is undertaken because of marketing and production cost advantages. For example a firm may expand downstream or upstream, although such specific detail is not part of the discussion. But organisational jumping is inevitably uncertain for two reasons. First, not all firms have the entrepreneurial capabilities to perceive and carry out a step change in organisational size. In a life-cycle context, the most dynamic first movers will jump first. This allows second, third etc movers to learn from first mover efforts. In short, a diffusion of knowledge about development opportunities is assumed to take place. This is analysed below by using a probability of jumping. Early in a life-cycle this probability is small, and later it is larger because of learning and knowledge diffusion. The second reason for uncertainty with effort jumping follows from the first reason. Because organisational development is analysed as a stochastic process it is impossible to predict future competition. Hence even if a firm jumps, the organisational investment may fail because of future non-viability. It is shown below that an analytical structure of this sort generates simulation output consistent with standard ILC patterns.

The use of a simulation based method suggests that the analysis presented here has much in common with agent based modelling and agent based computational economics. This general area has grown considerably in recent decades, not least because of the general availability of powerful computer technology. Within economics, or specifically with regard to analysis of the firm, such methods are useful to analyse complex, interacting systems in which discrete events, or non-continuous factors (for instance the organisational "jumping" used here), are central to analysis along with stochastic dynamics but when descriptive validity is important (Holland and Miller, 1991). For current purposes the most useful models are those grounded on standard analytical principles, for example transaction costs (Klos and Nooteboom, 2001), monopolistic competition (Seker, 2012), or the current analysis that uses Cournot modelling. But a key advantage of simulation methods is that agent heterogeneity, along with step change, can be introduced. For example Seker (2012) uses R&D based firm differences and the current discussion uses firm specific organisational step change. This indicates the potential importance of simulation methods for the analysis of industry life cycles.

The rest of the discussion is organised as follows. In the next section a background discussion of ILC analysis is presented. This is in not intended to be generally representative of this enormous literature but instead is selective and sufficient to orient later discussion. Following this review the theoretical framework is developed and analysed. This leads onto a consideration of simulation methodology and simulation results. Finally conclusions are drawn.

<u>Industrial dynamics and ILCs: background</u>

Over the last few decades, the literature on competitive strategies and analysis of firms has exploded in the domain of industrial dynamics (see for instance Turuk and Ofek, 2012; Spulber, 2010; Colombo and Delmastro, 2002; Lach and Rob, 1996; Dutta and Lach, 1995). Industrial dynamics can be generally defined as the study of the means and processes through which industries change over time. Within the industrial dynamics literature, the ILC analysis advances that some industries reveal special dynamics moving through intrinsic upturns and downturns known as cycles.

The recognition of industry dynamics is a far from recent occurrence (for discussion on this, see Geroski, 1995; Malerba and Orsenigo, 1997: Sutton, 1998; Dietrich and Krafft, 2012). In terms of modern understanding we point to the work of Schumpeter (1934, 1942) and Marshall (1920, 1925) as being the founding fathers. From these early authors' contributions, there are alternative reasons why an ILC and a shakeout (which is a key element of the emergence of a cycle in the ILC) may occur. First, technology essentially drives the life cycle of an industry, and is responsible for the shakeout. This calls to mind Schumpeter's vision of creative destruction in industrial dynamics. An entrepreneur sets up a firm to introduce his invention. This firm grows and holds a monopoly position for some time, but this firm is imitated by new entrants that compete with and eventually outperform the initial firm. This situation can last until another entrepreneur develops a new project involving the exit of older and larger firms and the entry of new ones. But we can also think about the shakeout in a different manner. We can consider that knowledge and competencies drive the life cycle of the industry. In that case, closer to Marshall's vision, the growth of knowledge is linked to the ability of firms to ensure coherence between internal economies (organization and direction of the resources of the firm) and external economies (general development of the economy, including the role of firms in the neighbourhood). From this perspective, the shakeout affects firms differently, since some firms might have the opportunity to accumulate specific knowledge and competencies to grow in size and survive.

In the 1980s, Gort and Klepper (1982) examined the long-term evolution of innovative industries, and assessed that this long-term evolution is essentially characterized by a life cycle in which industries, like bio-organisms, arise in their birth phase, grow and mature in their development time, and decline in their death phase. The ILC clearly added value to the explanation of a large number of regularities occurring in innovative industries: production increases in the initial stages and declines in the final stages; entry is dominant in the early phases of the life cycle and is progressively dominated by exit (a massive process of exit - a shakeout - occurs in the final stages of the life cycle); market shares are highly volatile in the beginning, and tend to stabilise over time; product innovation tends to be replaced by process innovation; first movers generally have a leadership position which guarantees their long-term viability; product variety disappears over time, as a dominant design emerges.

One of these regularities, i.e. the shakeout, progressively became a central regularity to be explored in industrial dynamics and contributions in the 1990s attempted to clarify when and why a shakeout occurs. At the empirical level, Klepper and Graddy (1990) confirmed that in the 46 industries considered by Gort and Klepper (1982) production is increasing when the life cycle starts and is decreasing thereafter. Klepper and Miller (1995) refined the definition of a shakeout and found that only 27 industries out of the 46 initially considered faced a shakeout. Much interest has been devoted also to the first mover's hypothesis. Agarwal and Gort (1996) showed that first movers tend to avoid the shakeout as their entry date corresponds to the moment when exit rates are the lowest. Green et al. (1995) also document that first entrants usually gain larger market shares than later entrants, and for a greater number of products. At a more conceptual level, the literature also focused more and more on the shakeout phenomenon, and attempted to clarify what occurs in pre-shakeout versus post-shakeout periods (Klepper, 1997). This attention is of course related to the crucial role of shakeout in the industry life cycle: a cycle cannot be observed without a shakeout in mature stages of the industry. But shakeout is also a key to understanding why a given industry is declining, and why major actors of this industry tend to be superseded by new actors creating a new industry. Behind this, there is the idea that a given technology can create profit opportunities for some time, but that new technologies will recurrently be created and replace older ones. This Schumpeterian vision of the dynamics of an economic system has been explored in contributions on the shakeout in industry life cycle, with an emphasis on different determinants from a purely external technological shock (Jovanovic and McDonald, 1994) to more endogenous arguments related either to the development of knowledge at the level of the firm (Abernathy and Utterback, 1978; Abernathy and Clark, 1985) or the timing of entry and the costs of firm growth (Klepper, 1996).

For Jovanovic and McDonald (1994), shakeout is generated by an external technological shock, exogenous to the industry. The first technological shock sets in with the development of the new product being launched on the market. Entry is stimulated by the emergence of new profit opportunities related to this new technology/new product, but subsequently there is a progressive reduction in profit margins and the industrial structure stabilizes on a limited number of firms in the industry. At this stage, which corresponds to the maturity of the industry, a new technological trajectory emerges and again stimulates the process of entry, in the meantime, involving an adjustment of incumbent firms. The process of adjustment is driven by a stochastic process and only a few firms survive this external shock. The shakeout thus eliminates firms which failed to adapt themselves to the new technology.

Alternatively, Abernathy and Utterback (1978), and Abernathy and Clark (1985) have developed an analysis of shakeout and dominant design. When a firm launches a new product in the market, it must face a high level of uncertainty affecting both the conditions of demand and supply. On the demand side, uncertainty comes from the fact that the firm does not know the details of customers' preferences. On the supply side, the conditions of production are also highly uncertain and may evolve over time. Over time, uncertainty decreases and selection operates. On the demand side, uncertainty decreases once customers of the new product have tested the alternative characteristics, and acquired experience on what they expect from the new product, which characteristics are more adapted to their personal taste and usage. On the supply side, rival producers learn over time and accumulate experience on what customers prefer. In time they also select a series of production techniques which are adapted to low cost production. Since uncertainty decreases, the shakeout appears as an endogenous phenomenon. Product innovation diminishes because most of the actors (producers and customers) are naturally oriented towards the production and consumption of a standardized good. The progressive emergence of a dominant design involves higher barriers to entry which correspond with investments by incumbents in process innovation. Entry is thus limited, and less efficient incumbent firms exit the industry.

Finally, Klepper (1996) relates the shakeout to the timing of entry and first movers' expansion costs. The reference is, here again, the Schumpeterian hypothesis on the relation between firms' size and R&D capacity. But the novelty is that this hypothesis is discussed on the basis of a finer distinction between firms which can eventually be incumbent, new entrant, or latecomer. Process innovation decreases the average costs of large firms, which are the major actors of this type of innovation. However, some key elements may erode the advantage of larger firms. For instance, large firms have to cover specific costs, such as expansion costs, which limit their growth. The activity of R&D can also exhibit decreasing returns to scale over time. Because of these elements, early entrants can develop process innovations, sometimes much better than incumbents or latecomers. Early entrants can thus enjoy a leadership position in process innovation as, on the one hand, incumbents have to deal with other problems which are related to their large size and, on the other hand, latecomers have to concentrate on product innovation which allows them to grow to a minimum size in order to survive. The timing of entry is thus a major determinant in the formation of a competitive advantage over incumbents, as well as in long term survival over latecomers. This mechanism provides an alternative explanation of the shakeout.

The present paper's contribution to the extant literature is the following. First, Schumpeter's emphasis on linkages between entrepreneurship and innovation lies in the analytical background of the current discussion, and hence is not considered explicitly, because we assume an unchanged structure for demand and cost parameters. It is shown that even with this non-Schumpeterian characterisation ILC effects can be generated. The current framework is more Marshallian in emphasis because it posits an increasing chance of undertaking an organisational step change, or developmental leap, as life cycles mature. The changing chance of attempting this leap, that is core to the analysis, is viewed as being determined by a knowledge diffusion process. Early in a life-cycle only the most dynamic firms will attempt the organisational investment involved, but later as knowledge of such possibilities diffuses, the chance of attempting an organisational leap increases. This approach is consistent with Marshall's emphasis on the organisation of knowledge as important for analysis.

Second, in terms of more recent writing Gort and Klepper (1982), Klepper (1997) and Abernathy and Utterback (1985) present the basic characteristics of ILC analysis. Entry (and exit) dominate in early stages of cycles with resulting unstable market shares. Following a shakeout, later life-cycle stages have more stable market shares with reduced entry and exit. These key differences pre- and post-shakeout are seen to emerge in simulations undertaken below. In Gort and Klepper (1982) and Abernathy and Utterback (1985) entry slows down because of either i) the accessibility of information to develop innovation or ii) a learning process that drives the consumers and producers to select the best products / the best processes. We borrow from this tradition by linking the probability of organizational step change pre- and post-shakeout to knowledge diffusion.

Third, to explain ILC evolution, and in particular the shakeout, Jovanovic and McDonald (1994) use the idea of a stochastic shock. We use this tradition and introduce a stochastic process as the motor of change. But there is a key difference between the current and previous work. The Jovanovic contributions view the shock as being technological with new profit opportunities being related to new products or processes. In the current framework the stochastic input determines organizational step change rather than technological opportunities. This step change has advantages in terms of demand and production costs. But ignoring the differences, the shock in both approaches has demand and process benefits with consistent effects: markets stabilize and relatively few firms survive the shock.

Fourth, one further contribution to the ILC literature is worthy of note. The approach of Klepper (1996) introduces the cohort effect that leads late entrant firms to be successful as well as early entrants. Hence the timing of entry is important because small, first entrants are not necessarily the leaders of the industry as at some stage they face the burden of growth in their size. Entrants that get into the industry at a later stage may finally outperform the first entrants. We have a form of this cohort effect. The intensity of future competition cannot be predicted in the framework set out below, so the first firms to undertake the step change in organizational investment may fail because of later entrants, even though there are demand and production cost benefits from the investment. Later firms that attempt the developmental leap may benefit from the feature that even though there is competitive uncertainty post shakeout this is less intense and furthermore (eventually) a steady state emerges.

Theoretical framework

The key theoretical addition to the oligopoly framework presented here is to include organisational effort, as well as firm output, as a choice variable. This addition allows us to link the framework to ILC analysis. Because of its centrality to the analysis, discussion in this section starts with how organisational effort is conceptualised. For any real firm, organisational activity is made up of many specific human and non-human inputs that are used to manage and control output and input markets as well as intra-firm functions. In addition, once again in practice, there will be specific substitutabilities and complementarities between the organisational inputs. To conceptualise this complexity we assume that all organisational inputs are used in fixed proportions. This assumption allows us to view a firm's organisation as a "basket" of inputs. The internal structure of the "basket" is fixed but the size of the basket can be varied in a continuous manner. This size of the basket defines the organisational effort for firm i (e_i) and the accompanying organisational overhead cost (oc_i). Hence we can specify a generalised organisation cost function:

$$oc_i = f(e_i) \qquad [1]$$

It follows from the fixed proportions assumption that the function $f(e_i)$ is linear, a specific form of which is used below. In addition, it follows from the fixed proportions organisational technology that we can measure e_i in terms of any of the inputs, e.g. organisational labour hours. The choice of input will merely affect the scaling. Furthermore, this allows us to construct a measure of competitor aggregate organisational effort (e_{-i}), at least in principle.

Organisational effort is viewed as having an impact on two areas of firm real activity: sales and production costs. Increasing e_i has a positive impact on demand and/or price. But because of the oligopoly framework, the efforts of competitors (e_{-i}) are assumed to have a negative impact on demand and/or selling price the extent of which depends on product differentiation. The impact on production costs operates because of greater organisational control and/or more effective management of input markets. Hence there is an assumed non-positive relationship between e_i and average production costs.

The framework uses a linear inverse demand function for a single product with (potentially) product differentiation and a generalised number of firms. For firm i:

$$p_i = \alpha - \beta x_i - \gamma x_{-i} + \delta e_i - \varepsilon e_{-i} \qquad [2]$$

Firm's selling price is p_i, x_i is output produced, x_{-i} is competitor output. The key addition to the inverse demand function is the inclusion of firm i organisational effort (e_i) and competitor effort (e_{-i}). The parameters α, β, γ, δ and ε are positive constants.

Firm's unit production costs are a function of output (in the standard way) and organisational effort with the same functional form assumed for all firms:

$$\bar{a}_i = \bar{a}(x_i, e_i) \qquad [3]$$

We assume constant returns to scale: $\partial\bar{a}_i/\partial x_i = 0$. This assumption allows us to concentrate on organisational activity and the ways in which it links with real activity as determinants of ILC effects rather than these effects being influenced by production based returns to scale directly. It follows from earlier discussion that $\partial\bar{a}_i/\partial e_i \leq 0$. Total costs for firm i are the sum of production costs and the organisational overhead:

$$tc_i = x_i\bar{a}(x_i, e_i) + f(e_i) \qquad [4]$$

We assume all firms face the same symmetrically differentiated inverse demand [eq 2], and have the same average production and organisation cost functions but because x_i and e_i need not be the same for all firms (see below) the same functional forms can result in different production and organisation costs.

Beyond the short-run, firm i's profits must be non-negative for viability:

$$\pi_i = \alpha x_i - \beta x_i^2 - \gamma x_i x_{-i} + \delta e_i x_i - \varepsilon e_{-i} x_i - \bar{a} x_i - f(e_i) \geq 0 \qquad [5]$$

This profit-viability constraint is no more than an economic truism. To give it explanatory content we must account for the determination of the choice variables: x_i and e_i. We use, in the standard manner, myopic profit maximisation. Any more sophisticated assumption is rendered non-viable because the stochastic input to the analysis (discussed below) implies that future competition, i.e. the future impact of x_{-i} and e_{-i}, cannot be known. But we assume that current levels are observable. Maximising profit with respect to x_i and e_i:

$$\frac{\partial \pi_i}{\partial x_i} = \alpha - 2\beta x_i - \gamma x_{-i} - \gamma x_i \frac{\partial x_{-i}}{\partial x_i} + \delta e_i - \varepsilon e_{-i} - \bar{a} - x_i \frac{\partial \bar{a}}{\partial x_i} = 0 \qquad [6a]$$

$$\frac{\partial \pi_i}{\partial e_i} = \delta x_i - \varepsilon x_i \frac{\partial e_{-i}}{\partial e_i} - x_i \frac{\partial \bar{a}}{\partial e_i} - f'(e_i) = 0 \qquad [6b]$$

We assume Cournot conjectures for both output and effort: $\partial x_{-i} / \partial x_i = \partial e_{-i} / \partial e_i = 0$.

Using the condition for profit maximising output [6a], and the Cournot and constant returns assumptions:

$$x_i = \frac{\alpha - \bar{a} - \gamma x_{-i} + \delta e_i - \varepsilon e_{-i}}{2\beta} \qquad [7]$$

It is clear that [7] defines an output reaction function: firm i observes x_{-i} to formulate its own output. But x_i also depends on organisation effort decisions of all firms. Hence to solve for x_i we must solve for organisational effort.

To define a condition for e_i, re-arrange [6b], the effort profit maximising condition:

$$x_i = \frac{f'(e_i)}{\delta - \partial \bar{a} / \partial e_i} \qquad [8]$$

Set [7] = [8] i.e. $x_i = x_i$ and re-arrange:

$$e_i = f'(e_i) \frac{2\beta}{\delta(\delta - \partial \bar{a} / \partial e_i)} - \frac{(\alpha - \bar{a} - \gamma x_{-i} - \varepsilon e_{-i})}{\delta} \qquad [9]$$

Formulation [9] defines an implicit (see 11d below) effort reaction function. Firm i observes e_{-i} and determines e_i given the fundamentals of the model and x_{-i}.

We use the condition for profit maximising output [7] to remove x_i from the viability condition and re-arrange:

$$\alpha - \bar{a} - \gamma x_{-i} + \delta e_i - \varepsilon e_{-i} - 2\sqrt{\beta f(e_i)} \geq 0 \qquad [10]$$

We have two fundamental conditions that define the nature of the framework. (1) A viability constraint [10] that incorporates the production of profit maximising output. This constraint is a function of e_i, competitor activity and the fundamentals of the model. (2) A profit maximising condition for firm effort [9] that is determined by the fundamentals of the model and competitor activity. To use these two conditions we have to recognise that production and organisation costs are themselves functions of e_i. Hence any solution depends on the particular form these functions take.

To solve the system we make the following assumptions. First, organisation costs are a linear function of effort (this follows from earlier discussion):

$$f(e_i) = \eta e_i \qquad [11a]$$

Hence:

$$f'(e_i) = \eta \qquad [11b]$$

Secondly, we assume a constant elasticity form for average production costs with the assumed constant returns to scale:

$$\bar{a}_i = x_i^0 e_i^\zeta \qquad \zeta \le 0 \qquad [11c]$$

Hence:

$$\frac{\partial \bar{a}_i}{\partial e_i} = \zeta e_i^{(\zeta-1)} \qquad [11d]$$

Using these formulations the viability constraint is defined by:

$$\delta e_i - e_i^\zeta - 2(\beta \eta e_i)^{0.5} + (\alpha - \gamma x_{-i} - \varepsilon e_{-i}) \ge 0 \qquad [10a]$$

Equilibrium effort requires:

$$\begin{aligned} &\delta^2 e_i - \delta(\zeta+1)e_i^\zeta - (\alpha - \gamma x_{-i} - \varepsilon e_{-i})\zeta e_i^{(\zeta-1)} + \zeta e_i^{(2\zeta-1)} - \\ &[2\beta\eta - \delta(\alpha - \gamma x_{-i} - \varepsilon e_{-i})] = 0 \end{aligned} \qquad [9a]$$

To simplify presentation we formulate these two conditions in general form:

$g(e_i) \ge 0$ being the viability constraint [10a];

$h(e_i) = 0$ being the condition for profit maximising effort [9a].

Initially consider the viability constraint [10a]. Defining the first derivative:

$$g'(e_i) = \delta - \zeta e_i^{(\zeta-1)} - (\beta\eta)^{0.5} e_i^{-0.5} \qquad [12a]$$

With ζ=0 (i.e. the assumed upper bound for the effect of effort on production costs) [12a] can be positive or negative at small e_i depending on the relative sizes of the first and final terms. As e_i increases the final term decreases in size hence a positive initial $g'(e_i)$ will continue positive but a negative initial derivative will (eventually) switch sign. With larger (in absolute terms) ζ the second term in [12a] is positive but decreasing in e_i hence this does not change the general conclusions just drawn: the constraint may have an internal peak or be downward sloping as e_i increases. Hence if the constraint is binding at profit maximising e_i this can apply to both small and large organisational size. Note this conclusion is driven by organisational factors as we have assumed constant returns in production. Also note the rather obvious feature that an increasingly competitive environment shifts the overall constraint downwards, because of e_{-i} and x_{-i}, and hence may render it binding for both small and/or large firms.

Turning to the condition for profit maximising effort: $h(e_i)$ [9a]. To see the general characteristics of this formulation we can define the first and second derivatives:

$$h'(e_i) = \delta^2 - \zeta\delta(\zeta+1)e_i^{(\zeta-1)} - \zeta(\zeta-1)(\alpha - \gamma x_{-i} - \varepsilon e_{-i})e_i^{(\zeta-2)} + (2\zeta-1)\zeta e_i^{(2\zeta-2)} \quad [12b]$$

$$h''(e_i) = -(\zeta-1)\zeta\delta(\zeta+1)e_i^{(\zeta-2)} - \zeta(\zeta-1)(\zeta-2)(\alpha - \gamma x_{-i} - \varepsilon e_{-i})e_i^{(\zeta-3)} + (2\zeta-2)(2\zeta-1)\zeta e_i^{(2\zeta-3)} \quad [12c]$$

As a benchmark consider, again, the case of $\zeta=0$:

$$h'(e_i) = \delta^2 > 0 \quad [12b']$$

$$h''(e_i) = 0 \quad [12c']$$

An initial technical point is that this value of ζ should be viewed, in a literal sense, as a limiting case. The reason for this is that if we assume constant returns with respect to x_i and e_i unit production costs do not vary in the framework. This feature along with the overhead organisation costs that exist present maximisation problems. Hence we should view [12b'] and [12c'] as being relevant as $\zeta \rightarrow 0$. It is clear that as $\zeta \rightarrow 0$, $h(e_i)$ becomes linear with positive slope. It follows that as long as $h(e_i)$ is negative with small e_i there is a unique solution for organisational effort, the nature of which is considered further below. From the definition of $h(e_i)$ in [9a], negative values at small e_i can be guaranteed with sufficiently large η i.e. with sufficiently large overhead organisation costs. This is perhaps a not surprising conclusion.

The nature of $h(e_i)$ with strictly negative ζ is less obvious. Consider first the impact of e_i on $h'(e_i)$ in [12b]:

– $\zeta\delta(\zeta+1)$: with $\zeta < -1$ this is negative;

– $\zeta(\zeta-1)$ is negative, in addition $\alpha-\gamma x_{-i}-\varepsilon e_{-i}$ is positive for firm viability;

+ $(2\zeta-1)\zeta$ is positive.

Hence we might expect a non-monotonic $h(e_i)$, particularly with large absolute ζ.

For $h''(e_i)$ in [12c]:

– $(\zeta-1)\zeta\delta(\zeta+1)$: with $\zeta < -1$ this is positive;

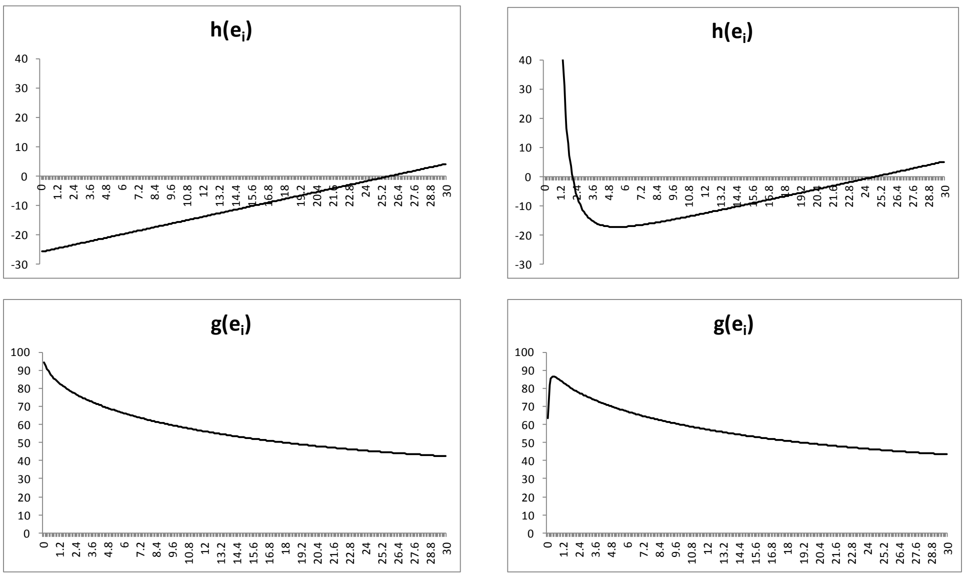
– $\zeta(\zeta-1)(\zeta-2)$ is positive;

+ (2ζ-2)(2ζ-1)ζ is negative.

The most general conclusion is that with sufficiently large absolute ζ the combined effect here is positive. This guarantees a maximum of two solutions for $h(e_i) = 0$. Note an arithmetic issue here is that at very small, but positive, effort $h(e_i)$ can be unstable in the sense that $h'(e_i)$ can change sign with very small changes in e_i. The reason for this is that with very small e_i (close to zero) the overall effect is sensitive to the impact of negative exponents. To avoid this instability caused by arithmetic factors that have little economic significance, the lower bound for effort is taken to be above zero, with the exact lower bound depending on parameter values.

To illustrate these general conclusions, and the analytical features the more thorough-going analysis undertaken below must incorporate, we will initially assume $x_{-i} = e_{-i} = 0$ i.e. that a single firm exists. We also assume that ζ can take one of two values: 0 and -1.5 that reflect (respectively) no and significant impact of effort on production costs. We also assume the following: $\alpha = 100$; $\beta = 1.25$; $\gamma = 0.5$; $\delta = 1$; $\varepsilon = 0.5$; $\eta = 50$. These parameter values ensure that solutions for e_i and x_i exist and illustrate the key features of the framework as shown in Figure 1.

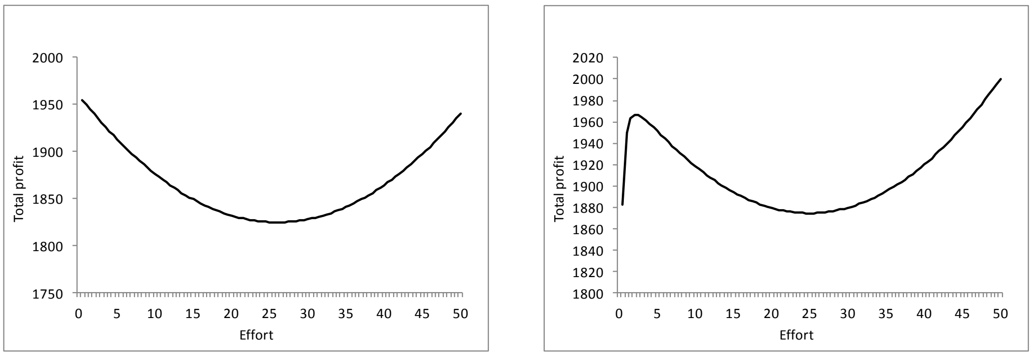
Figure 1: Determination of effort and viability (single firm)



In Figure 1 each diagram shows e_i on the horizontal axis and $h(e_i)$ or $g(e_i)$ on the vertical axis. The left hand diagrams show the conditions for ζ=0 and the right hand diagrams for ζ=-1.5. The diagrams should be interpreted in the following way. The top diagram shows the effort solution where the function, $h(e_i)$, is equal to zero. This value of e_i is then mapped to the bottom diagram to indicate the solution for the viability constraint. In the top left diagram there is a single e_i solution but in the top right there are two solutions In short large (absolute) ζ produces two solutions that we describe as small and large organisation size.

Having derived the key result that two organisational sizes can exist in the framework used here, we must now recognise that these two effort solutions are different in a fundamental sense not just the sizes involved. Consider Figure 2 that shows total profits at different effort levels for the two cases of ζ being zero (on the left) and -1.5 (on the right). Consider first the case of ζ=-1.5. The small effort solution is clearly an internal profit maximum. But the large effort solution is not an internal maximum but is rather an internal minimum. For effort levels greater than this second solution the profit function is monotonic positive i.e. profits can be greater than the small effort solution as long as organisational capacity is sufficiently large. Hence this large effort solution is a minimum size beyond which large organisations can maximise profits (depending on organisational capacity). Instead of introducing a corner solution into the analysis conducted here, i.e. the actual profit maximising effort level for a large firm depending on an (unspecified) organisational capacity constraint, we will maintain the shorthand that the large internal solution is a minimum required size beyond which actual organisational size (and profitability) is unconstrained. In the left hand diagram in Figure 2 (i.e. ζ=0) we can see that the single effort solution is the minimum large size.

Figure 2: Total profits and organisational effort.



The following features of this framework are also worthy of note. First, as we have an assumed single firm, monopoly rent exists. This is indicated by $g(e_i)>0$ in both sets of diagrams at the profit maximising levels of effort. Secondly, firms can "jump", in effect make a developmental leap, if they want to shift from small to large firm solutions. This step change in organisational investment will have demand and production cost benefits (the latter with strictly negative ζ). This possibility is examined in detail below. Also note that the single (in the left diagram) and large (in the right) solutions for e_i are approximately the same.

Finally, with firm entry both $g(e_i)$ and $h(e_i)$ are affected. The viability constraint shifts down. Hence with increasing e_{-i} and x_{-i} we can expect (eventually) a marginal firm to have a zero profit solution. This feature applies to both small and large organisations in the right diagram. The impact of e_{-i} and x_{-i} on $h(e_{-i})$ involves two effects. First, increasing e_{-i} and x_{-i} causes the curve to shift down because of $-[2\beta\eta-\delta(\alpha-\gamma x_{-i}-\varepsilon e_{-i})]$. Secondly with $\zeta<0$ the curve changes shape because of $-(\alpha-\gamma x_{-i}-\varepsilon e_{-i})\zeta e_i^{(\zeta-1)}$. Increasing e_{-i} and x_{-i} reduces this positive effect of e_i. The combined effect here is two-fold. First, both small and large e_i fall (a rather obvious effect of increasing competition). Secondly, the solutions indicated by the top right hand diagram, in Figure 1, may change. As the only relevant solutions cover non-negative e_i, the downward sloping part of the curve can become irrelevant. In effect the framework can switch from two solutions to a single solution model. The consequences of this switch are explored below. Note that it occurs without any changes in the fundamentals of the model but is an effect of changing competition.

<u>Simulating industry life cycles: background and method</u>

In this section the discussion turns to how the framework developed above can be used to explore ILCs. This application to industry evolution is done in two stages: a basic framework followed by a more developed analysis that allows any firm to make a developmental leap. All simulations use the same parameter values used in the previous section to generate Figure 1 and with $\zeta=-1.5$. Among other things this allows the two level effort solution reported above. All parameters are assumed constant, apart from one exception reported below.

Three key features of ILC analysis will be examined:

Can we track characteristic entry/exit decisions etc and how these change as life cycles mature?

Can a life-cycle "shakeout" be identified?

Can we track characteristic market structure evolution as displayed by firm numbers?

Initially a basic simulation is undertaken. The objective here is to show that the model behaves normally in what might be considered normal conditions. This allows us to judge the additional effect of non-normal simulation with a stochastic input. The simulation logic, for this basic first stage, is as follows.

1. All firms are constrained to be small size in terms of effort equilibrium. Sequential entry of these small firms is undertaken. A potential entrant calculates profit maximising effort as a small firm, and then profit maximising output, both given Cournot assumptions i.e. by observing e_{-i} and x_{-i}. If non-negative profits are possible it enters. When a new entrant cannot earn non-negative profits the first iteration is complete.
2. Iteration two works through firms sequentially with each firm observing e_{-i} and x_{-i} from iteration one or two as relevant. So, for example, the second firm observes the first firm's effort and output from iteration two but the third, and other firms effort and output from iteration one. This process is completed for all existing firms. Finally entry is allowed if this is viable.
3. Repeat with as many iterations as required.

We can justify the approach used here, involving the sequential consideration of firms, in one of two ways. First, it is a necessary feature to render the simulation analysis feasible. Secondly, it mimics a key feature of ILC analysis identified above: initially change is undertaken by the most perceptive first movers, followed by second then third etc movers. In short, the logic captures a key feature of ILC analysis with the only analytical assumption being that there are single first, second etc movers.

Following this basic simulation a second experiment is undertaken that allows firms to make a developmental organisation leap by jumping from small to large effort solutions, if the $h(e_i)$ function defines two solutions as being possible. In reality managing a step change in organisational size is complex and uncertain. But in terms of the formal modelling and simulation used here this complexity and uncertainty is analysed in terms of a stochastic process. We introduce a probability (ρ) of jumping from small to large effort solutions. The first iteration is the same as the basic simulation, i.e. no jumping is allowed and all firms enter at the small equilibrium. But from the second stage, as each firm is examined a random number is generated: r(0, 1). If $r < \rho$ the firm jumps otherwise it stays small. If a firm jumps this is irreversible i.e. it cannot jump back. But all firms, no matter what their size, exit if losses are made.

A particular interpretation of this stochastic approach is used here. It is somewhat standard in life-cycle analysis, as considered in the earlier review, to suggest that early in a cycle only the most entrepreneurial firm(s) will attempt a developmental leap of the sort suggested here. These first movers may or may not be successful but their efforts can provide demonstration effects upon which other firms learn about developmental possibilities. This suggests that an important characteristic of a life cycle is the diffusion of knowledge of developmental possibilities. In terms of the current framework, if there are limited possibilities for organisational development then ρ is small whereas as a life cycle matures, and knowledge diffusion takes place, ρ increases. As discussed in an earlier section, this interpretation of a changing ρ, in a life cycle context, suggests a rather Marshallian view of life cycle analysis. Here the key dynamic is knowledge use. The alternative, Schumpeterian, perspective suggests that life cycle dynamics are produced by fundamental innovation and entrepreneurship. For the current framework this innovation is part of the analytical background as it determines the fundamentals of the model.

Hence the stochastic approach used here, based on Marshallian reasoning, suggests that life cycle stages can be analysed in terms of a changing ρ; small ρ indicating early stages and larger ρ later stages. In principle two general approaches might be used here to accommodate changing ρ. The first might involve ρ changing endogenously with each iteration of a simulation from some lower bound and ending at some upper bound. This approach is not adopted here for two reasons. It is by no means obvious how we might define the shape of a changing ρ. For example a linear change in ρ suggests that learning and knowledge diffusion progresses in a smooth manner. This smooth diffusion would be an arbitrary assumption. Arguably any assumption here is arbitrary. The second reason for rejecting an endogenously changing ρ involves interaction of ρ with other model dynamics. The first, basic, simulation shows that we might expect an equilibriation process to occur. An increasing ρ might also generate an equilibriation process of its own but if this is superimposed onto later simulation iterations it is difficult to disentangle cause and effect.

For these reasons an endogenously changing ρ is not used here. Instead two values for ρ are assumed: 0.1 and 0.5. Simulations are undertaken at each value of ρ and the results compared. In terms of ILC analysis these two values of ρ are taken to define pre- and post-shakeout conditions because of the assumed limited and generalised diffusion of development possibilities. As the approach is stochastic ten simulations are conducted in each case. This number is sufficient to indicate the general character of the results. It will be seen that the results are remarkably consistent with standard ILC-based observations. The obvious conclusion, therefore, is that these observations can be generated by a changing probability of organisational development interpreted as knowledge diffusion.

Simulating industry life cycles: results

All simulations are based on 15 iterations (time periods) and a maximum of 45 firms. These constraints are a necessary part of the STATA do files used for the simulations but have no influence on clear conclusions. For the stochastic simulations ten different runs are combined each defined by a different seed to the random number generator. This combination allows clear conclusions to be draw. As stated above, parameter values are the same as those used to generate earlier diagrams so that two effort solutions are possible.

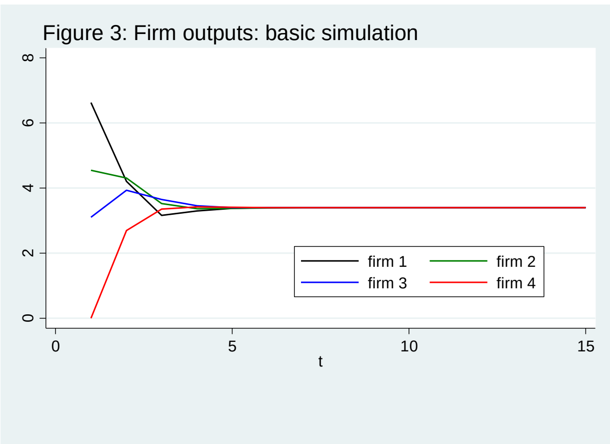


Figure 3 shows the firm outputs that result from the basic simulation. Initially three firms are viable (the fourth firm has a notional zero output in iteration one) but from iteration two four firms are viable. It is clear that the simulation rapidly reaches an equilibrium from iteration six. In addition, the model does not switch from the initial two effort variant of $h(e_i)$ to a single solution as firms adjust outputs and efforts i.e. the small effort equilibrium for each firm is not endogenously changed. In short the framework generates a standard Cournot-Nash equilibrium in standard (i.e. non-stochastic) conditions.

The following diagrams show results that allow for firms jumping from small to large effort solutions after iteration one. As discussed above two probabilities of jumping are used (0.1 and 0.5) representing early and later life cycle characteristics. In all cases the left hand diagram shows $\rho=0.1$ and the right hand $\rho=0.5$. Consider first the number of <u>viable</u> firms, ignoring whether they are small, large or the result of a single equilibrium.

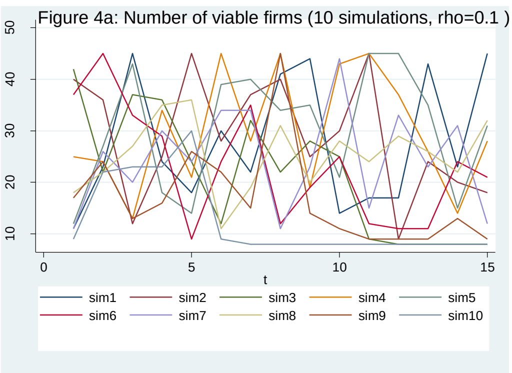


Figure 4a: Number of viable firms (10 simulations, rho=0.1)

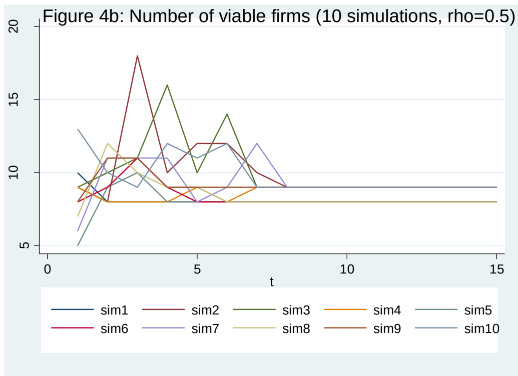


Figure 4b: Number of viable firms (10 simulations, rho=0.5)

It is clear from Figure 4a that early in a life cycle ($\rho=0.1$) there is considerable variation in the number of viable firms. Across the ten simulations these vary from less than 10 to the maximum of 45. For any one simulation the high degree of variability implies considerable entry and exit. Across all the simulations there is a high degree of survival uncertainty displayed by the results. In addition the stochastic input appears to undermine the achievement of any equilibrium. Figure 4b displays a markedly different set of results. Even though there is a higher stochastic threshold (ρ is 0.5 rather than 0.1) the survival uncertainty is much less apparent. In addition the framework achieves a steady-state after eight iterations i.e. there is no further firm entry of exit after this point. These results are remarkably consistent with standard life-cycle pre- and post- shakeout findings and are generated with no changes in fundamental model parameters apart from the probability of jumping organisational size.

A feature of Figure 4b that can be commented on is that two equilibria appear to exist i.e. there is no single steady-state solution for the number of viable firms. This is an example of a decision making result that Kaldor (1934) pointed out some time ago. When out of equilibrium decisions are made (as they are here prior to any steady state) multiple equilibria can result; using more modern terminology, path dependence can result. The specific reason for this in Figure 4b is that the stochastic input affects firm jumping and hence overall entry-exit decisions. Firm entry-exit is based on a viability threshold that is determined (in part) by x_{-i} and e_{-i}. In addition, jumping affects x_{-i} and e_{-i}. No two stochastic processes are identical in this respect. Hence the particular jumping time path produces particular firm viability results with the result being more than one steady state in terms of viable firm numbers.

The following three sets of figures break down the overall number of firms into three types: small, large and unique sizes. The latter size is a large firm single solution i.e. when the framework endogenously eliminates the possibility of a small firm equilibrium. An initial point is that these are total firm numbers that try to establish themselves some (indeed many in some circumstances) of which may not survive i.e. the firm numbers are different from the previous set of diagrams.

Figure 5a: Number of established small firms (rho=0.1)

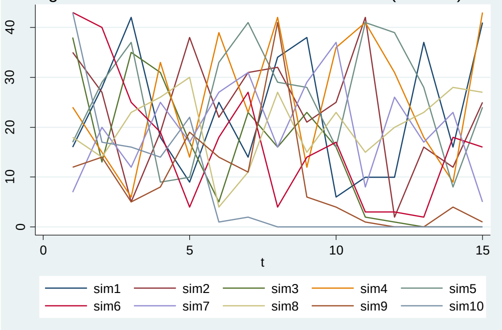
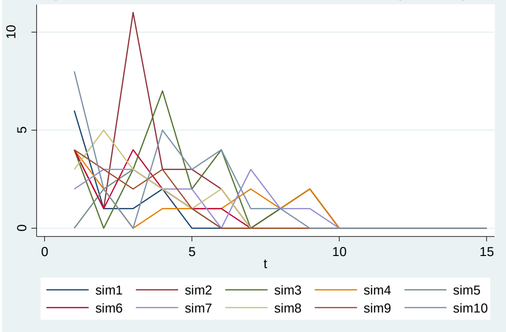
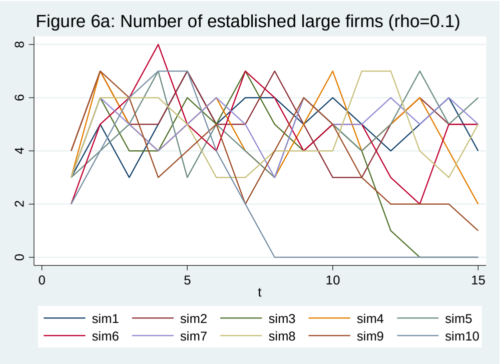
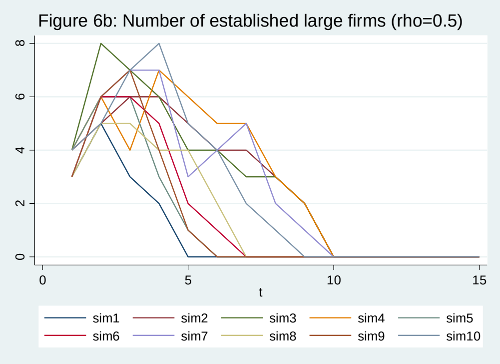


Figure 5b: Number of established small firms (rho=0.5)



The number of established small firms displays standard life-cycle characteristics pre- and post-shakeout. In Figure 5a (with ρ=0.1) there is considerable survival uncertainty for small firms whereas later in a life-cycle, in Figure 5b, small firms are eliminated from an industry. In addition with ρ=0.5 we can see that on average there is a declining trend in small firm numbers until a steady-state of zero is achieved. The results for large firm numbers (with a two effort solution), in Figures 6a and 6b, display a similar set of characteristics. With ρ=0.1 there is no obvious equilibrium, although the extent of survival uncertainty is smaller than for small firms. In the right hand diagram, i.e. for post-shakeout (ρ=0.5) there is an initial declining trend in large firm numbers followed by a steady-state of zero from period 10.





The similarity between results for large and small firms can be explained by the results for the unique sized firms shown in Figures 7a and 7b. In pre-shakeout conditions there is a high degree of survival uncertainty. From observation of the diagrams it is apparent that the extent of this uncertainty is of the same order as for small firms and greater than for large firms. But post-shakeout (ρ=0.5) there is on average an upward trend in unique sized firm numbers with a steady state of the maximum 45 firms from iteration ten. We can link the steady state result in Figure 7b with that found in Figure 4b. The earlier result indicated that fewer than ten <u>viable</u> steady state firms can exist. It is clear from Figure 7b that these viable firms are all unique (large) sized. It follows that we see the establishment, post shakeout, of a stable oligopoly with only large firms.

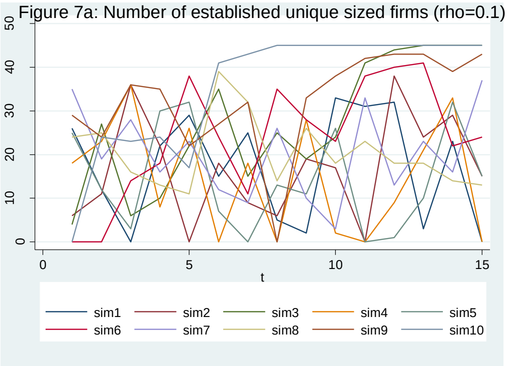


Figure 7a: Number of established unique sized firms (rho=0.1)

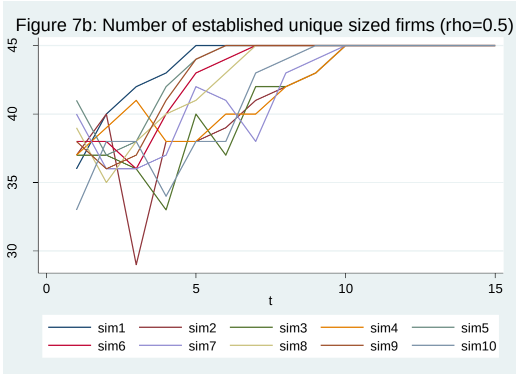


Figure 7b: Number of established unique sized firms (rho=0.5)

To reiterate a point made earlier, these results are generated with constant technical parameters that define demand and cost equations. The only factor changing is the probability of organisational development that can be interpreted as pre- and post-shakeout in a life-cycle context. The eventual elimination of small firms is achieved in a model with constant returns in production. The barrier to entry is generated by a change in the $h(e_i)$ function that switches from two solutions to one. In terms of standard industrial organisation, the rise of large firms with greater output squeezes small firms from the market because organisational costs are an initial capital requirement. But the resulting large firms that exist post-shakeout are not the result of organisational development i.e. not the result of an entrepreneurial leap. Instead because of a change in $h(e_i)$ they benefit from the single effort solution.

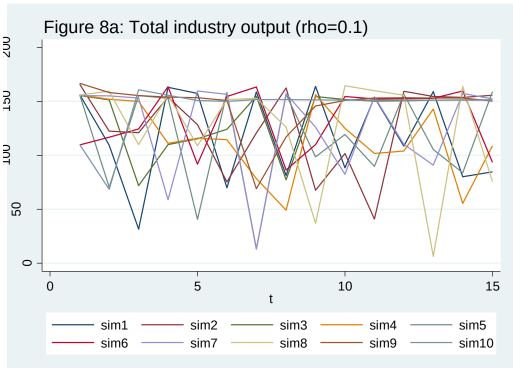


Figure 8a: Total industry output (rho=0.1)

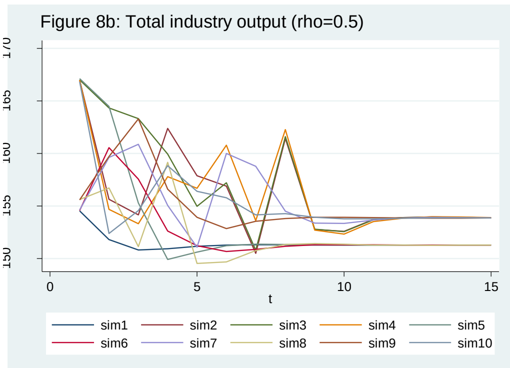
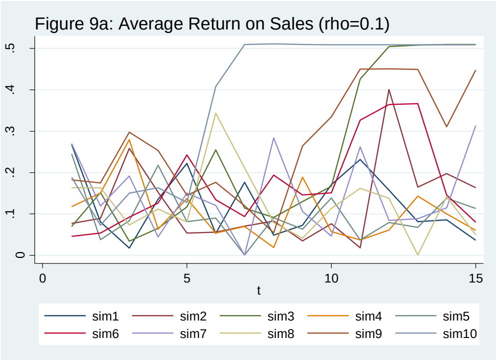
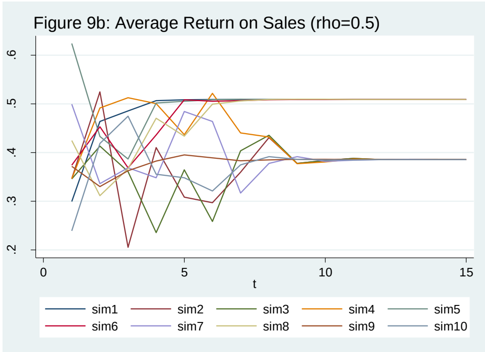


Figure 8b: Total industry output (rho=0.5)

The trends in firm numbers identified above have a somewhat predictable effect on industry output, shown in Figures 8a and 8b. The links here are (a) that a change in organisational effort produces a change in real output and (b) the variability in firm numbers. With ρ=0.1 there is significant variability in industry output and no apparent trend to an equilibrium. With ρ=0.5there is an evolution to a steady-state size but with no unique result. As considered earlier, the path dependence in industry output exists because of the multiple steady state solutions for the number of viable firms. In addition both average pre-steady state and steady state industry output appear greater with ρ=0.5 than the average with ρ=0.1 because of the development of oligopoly structure with large firms.





Finally consider Figures 9a and 9b that show average return on sales (π/px) for all viable firms for the ten simulations. To some extent these performance results simply reflect the discussion already undertaken. Prior to the shakeout average profitability uncertainty is high and varies from zero to 0.5. In addition the spread of the results (indicating the uncertainty) appears to be increasing with later iterations. After the shakeout the degree of uncertainty is lower and an eventual (but not unique) steady state is achieved with average return on sales being in the range 0.4-0.5. In addition note that the minimum profitability in Figure 9b is 0.2 not zero.

Conclusion

This paper has developed a simulation based model of ILCs. The analytical framework is grounded in a generalised Cournot model, but with a key development involving organisational effort, as well as physical output, as a choice variable. Effort is assumed to influence demand (positively) and average production costs (non-positively). It is shown that two effort solutions can exist, denoted small and large organisational size. This introduces the possibility that a firm can "jump" or undertake a developmental organisation leap from small to large solutions. This organisational jumping, to exploit demand and production cost advantages, is analysed here in terms of a probability and a stochastic process. A small probability (here 0.1) of jumping is viewed as knowledge of development possibilities being not generally diffused throughout the population of firms, a characteristic of an early (pre-shakeout) ILC. A larger probability (here 0.5) is taken to describe a more generalised diffusion of development possibilities, and so describes a post-shakeout ILC.

Simulation results are shown to be consistent with key features identified in the ILC literature: high levels of entry and exit and survival uncertainty with no apparent steady state pre-shakeout; whereas post-shakeout the development of a stable (steady state) oligopoly based on large firms. These results are derived with unchanged demand and cost functions and hence are driven by the probability of effort jumping. This analytical driver is interpreted as grounding the analysis in a Marshallian logic. The alternative Schumpeterian logic is precluded because of parameter stability. In short, a Marshallian inspired analysis can produce standard ILC effects in a developed Cournot model. This conclusion is not intended to imply a generalised irrelevance of a Schumpeterian analysis, instead it is intended to emphasise the constraints on the current analysis.

The analytical constraints involved with the modelling used here remove one ILC feature from the discussion. It is somewhat standard, as noted above, to identify a shift from product innovation pre-shakeout to process innovation post-shakeout. This feature cannot be recognised by the framework used here. In addition, recognising the analytical constraints indicates a possible future research agenda to include a more Schumpeter inspired analysis. One key assumption is critical in this respect: fixed proportions organisational technology. While this assumption is necessary in the context of the current framework, it prevents any shift of organisational effort from demand to production costs that might be interpreted as a shift in innovation. Hence possible future research might involve use of an organisational technology that allows substitution between marketing and production cost functions. If such a development was combined with diminishing returns to marketing efforts and/or increasing returns to production management, organisational jumping would then involve a shift in effort if organisational cost minimisation is assumed.

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