Cost competition between firms: system dynamics and other approaches

Michael Joffe

Imperial College London

41 Anson Road
London N7 0AR

tel: +44 20 7609 1470
fax: +44 20 7607 2446

email: m.joffe@imperial.ac.uk

Abstract

The role of system dynamics in modeling the fundamental properties of economic systems has been under-appreciated. The market mechanism displays balancing feedback, and bubbles are widely seen as reinforcing feedback. However, it is less widely understood that the exponential growth tendency in successful modern economies may represent a distinct type of reinforcing feedback.

This paper presents a system dynamics model of an arms race between competing firms based on cost competition, which displays reinforcing feedback: price reduction by one firm encourages the other to invest to reduce its costs and thence its price. The other firm responds in kind. Under these circumstances, costs and price of both firms steadily decline, mimicking the historic decline in real input required for a given product, e.g. measured in labor hours. This system behavior depends on the ability of both firms to respond to the competitor's price challenge by reducing its costs, but is robust to other changes in the firms (efficiency of investment) or in the market (price elasticity of demand). The ability to produce the same output with lower unit costs (reduced real inputs) is equivalent generating a larger output from the same resources, and is a major source of economic growth.

Key words

arms race, system dynamics, economic growth, capitalism, cost competition, productivity, cost reduction, price competition

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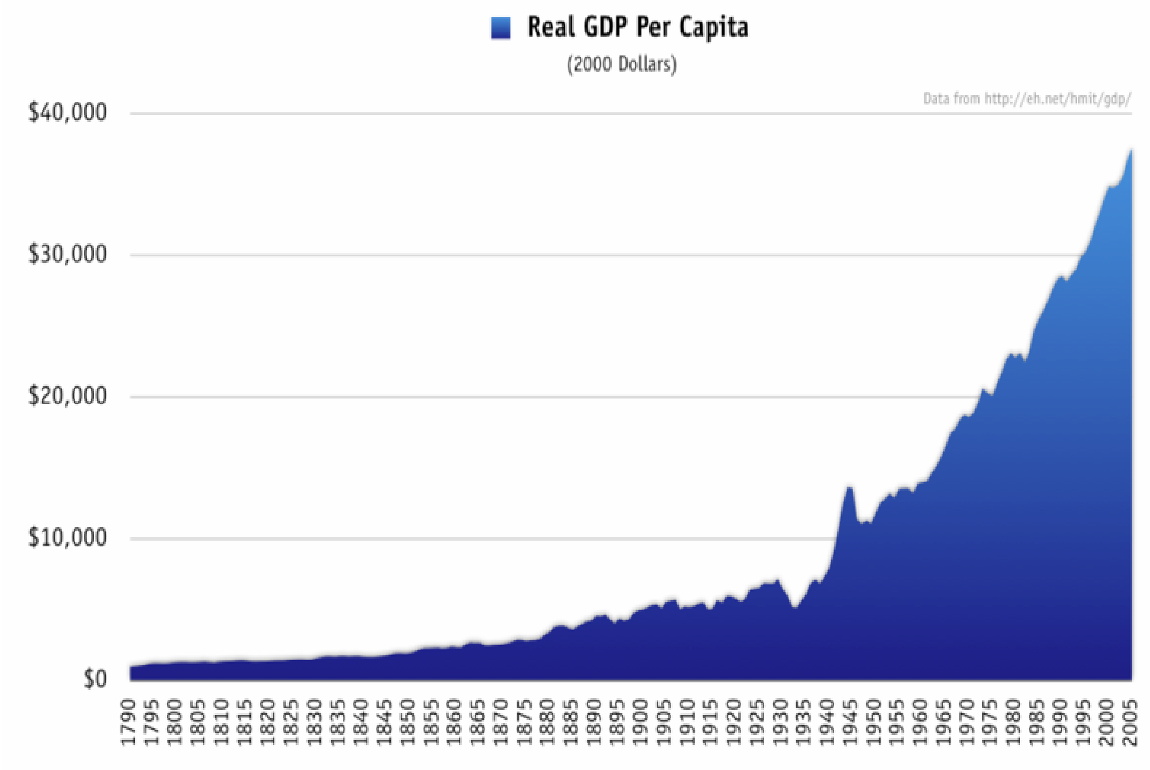
Introduction

The possible contribution of system dynamics to extending economic theory

System dynamics is highly successful in a wide variety of different applications, including in business studies. It has, however, been under-appreciated as a method for analysing the basic features of how the economy works – in other words, economic theory. There are good reasons to believe that it can make an important contribution: the US economy has shown almost perfectly exponential growth until the current downturn, despite fluctuations, over a period of 200 years (see figure), which makes it plausible that a reinforcing (positive) feedback process underlies the dynamics of modern economic growth. Current economic theory, whether based on exogenous technological change (Solow, 1956), "endogenous" spillovers (positive externalities) (Aghion and Howitt, 1997), institutions (Acemoglu *et al*., 2001) or evolutionary change (Nelson and Winter, 1982), do not predict this. Again, it is widely recognized that bubbles can occur in certain types of market, and that these reflect the type of reinforcing feedback known as a self-fulfilling prophecy (Shiller, 2005). In addition, the systems approach to economic theory would link with observations suggesting that certain aspects of the economy exhibit complex behavior patterns (Anderson *et al*., 1988; Arthur *et al*., 1997; Ormerod, 1998; Keen, 2001). If the more fundamental characteristics of the economy were analysed in terms of system dynamics and related methods of modeling, this understanding could help illuminate which economic phenomena are prone to complexity, and how it arises.



The financial and economic crisis has undermined the economics profession's confidence in some at least of its traditional methods, with responses that range from the incremental to the radical – see for example the contributions to the various conferences of the Institute for New Economic Thinking (INET, n.d.). There is now an opportunity for different approaches to be tried.

Economists universally acknowledge the importance of competition. Competition is closely related to profitability: it is generally agreed that the probability of survival of firms depends on their being able to generate a profit in the medium and long term; more generally, profitability can be regarded as a measure of the overall success of a firm. It is thus the firm's central imperative, and although it is in a sense exogenous in origin, it also forms a major goal for all those in management. Competition between firms is an important driving force: by threatening to erode margins, it motivates firms to take appropriate action to protect and enhance their profitability. It is, however, unusual for this competition to be modeled explicitly.

In contrast, a long tradition in economic theory has been to assume a particular type of market as an ideal type, for example a perfectly competitive market in which all firms are price-takers, or duopoly with either Bertrand or Cournot/Stackelberg competition, and to deduce the consequences. Another common assumption is that all firms in a sector have the same technology and therefore the same cost structure, as in standard textbook theory. The aim of this paper is to model between-firm competition explicitly, and to trace the effects not only on firms themselves but also more broadly on the sectors to which they belong, and on the economy more generally. In the long run, this could be a way to provide micro-foundations for the macro economy, without introducing the fallacy of composition.

Competition on the basis of cost

Competition can take various forms. In many sectors of advanced economies, the nature of the product is the major focus, for example the style, quality and branding of an item of clothing or of furniture. A second is competition on the basis of new products, such as pharmaceuticals.

A third, on which this model focuses, is less sophisticated: competition on the basis of unit costs and price. At the point of sale, the basis of competition is the price, as this directly influences customer decision making and thus the firm's market share. Behind the price is the firm's unit cost, as this jointly determines the price and the unit profit: a firm that has lower costs is able to reduce its price and still make a profit. It is therefore possible to distinguish *price competition*, in which firms with similar cost structures compete on the basis of price, thereby reducing their margins, and *cost competition*, which happens over a longer timescale, and involves firms cutting the real cost of their inputs.

Competition on the basis of cost rather than style etc or new products is more likely to happen with lower-value or lower-prestige products or services, with products for lower-income customers, and at an early stage in the economic development of a particular country – in Solow's words, "early ... or low-income capitalism" (Solow, 2006). This is because style, quality and branding tend to be associated with luxury and prestige, in other words competition on this basis tends to occur where the level of buying power is relatively high, at least for a substantial proportion of the population. The same is generally true of the introduction of new products: buying power has to be available, and it is cost-based competition that first creates the necessary prosperity (Joffe, 2012).

Cost competition can involve one or more of many different types of initiative: investment in a new production method such as a more productive machine, sourcing of lower-cost materials, organizational change to improve efficiency, etc. For present purposes, the particular way in which unit costs are reduced is ignored, the focus being on the consequences.

Different modeling approaches could be used to explore the behavior of firms competing on the basis of cost. For example, it would be possible to model the optimal decision in relation to the price elasticity of demand for the product. However, this may not capture the real behavior of competing firms, as shown by the attractiveness of such strategies as predatory pricing and loss leaders.

The approach taken here is based on the metaphor of an "arms race". In a literal arms race, military expenditure of one country leads its adversary(ies) to respond by increasing their own military budget, which in turn generates still more spending in the first country, a cycle that in principle can continue indefinitely (Richardson, 1960). Any temporary advantage that an individual country may enjoy is quickly eroded by the actions of its competitors, but ***at the aggregate level*** the overall effect is a build-up of armaments. The metaphor of an arms race has been widely applied to other situations, and it has been particularly successful in evolutionary biology (Dawkins, 2009).

In the current context, an arms race means that each company's investment threatens to erode the profit of its competitor(s), leading to a response in kind. Each competing firm constantly seeks to invest so as to reduce its costs. As in a literal arms race, it is necessary to distinguish the consequences for each competing firm (no enduring advantage for any of them) from the overall effect at aggregate level, which is that costs fall in that sector. The model is of a sector that consists of firms each represented by a single product line, thus ignoring economies of scope. The model also omits economies of scale. These could be introduced at a later stage.

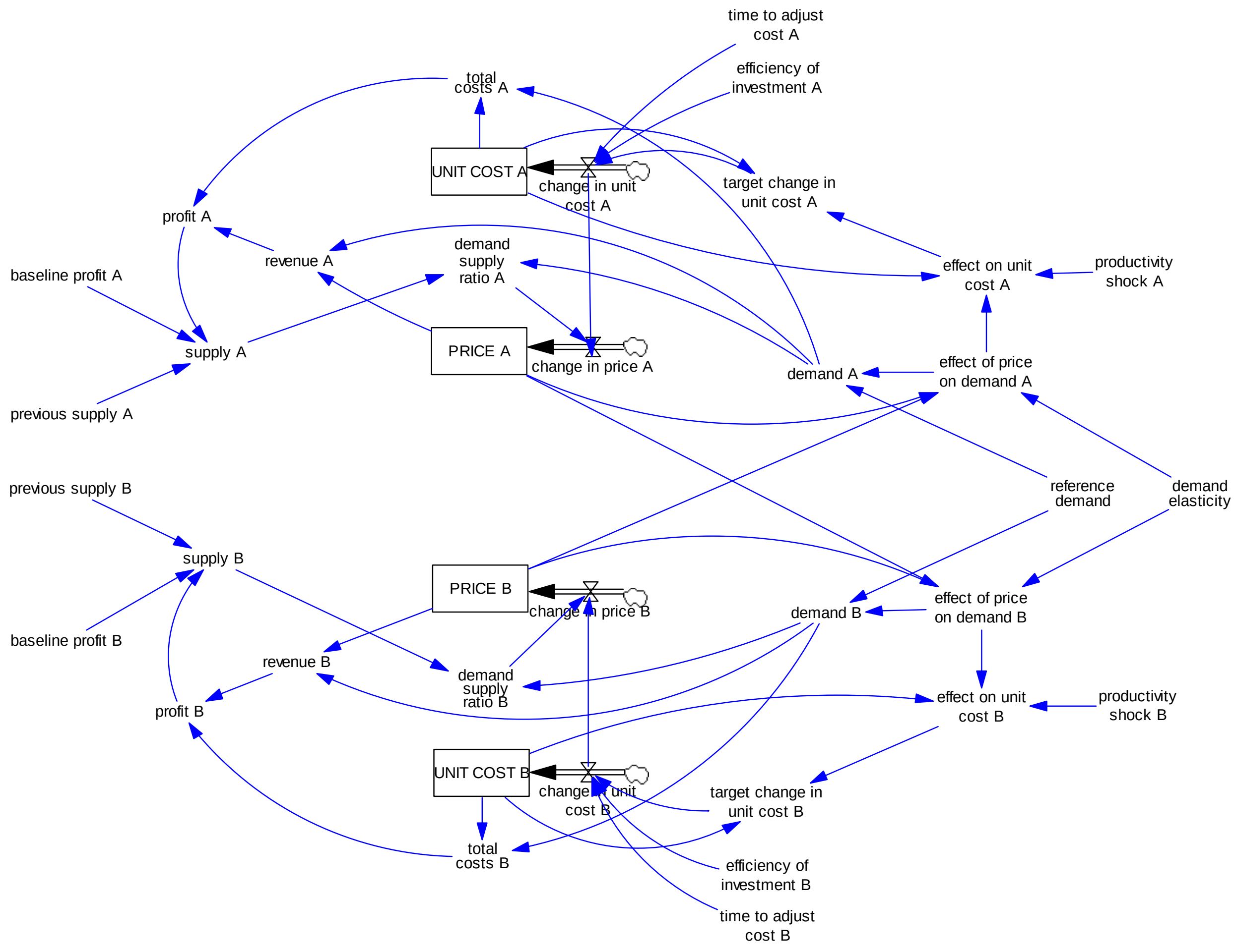
The system dynamics model

Basic structure

Modeling was carried out using Vensim PLE Plus for Windows version 5.9c. The initial model has been kept as simple as possible, in order to explore its basic dynamic behavior. At this stage the aim is to demonstrate the essentials of how cost-based competition operates, rather than to closely simulate its detailed behavior. The model is restricted to a single sector, consisting of two competing firms, initially assumed to be similar in all respects. This basic model could readily be extended in various ways – see the Discussion section.

The restriction to two firms is for model simplicity; this is not intended as a model of duopoly. Rather, the modeling strategy follows the recent theoretical and empirical literature in that it allows for varying degrees of competition, and maintains generality by not imposing Bertrand or Cournot (or Stackelberg) competition (Boone, 2008).

The basic features are that each firm's prices and unit costs are treated as stocks, with the price depending on the unit cost plus a proportional mark-up that depends on the demand/supply ratio. Unit costs are influenced by the prices of both firms through the investment decision. This is the point at which competition enters, because the price of each firm threatens the profitability, and even possibly the existence, of the other. This could be stated in terms of each firm's goal to stay ahead, or at least survive, in the struggle for continuing profitability.

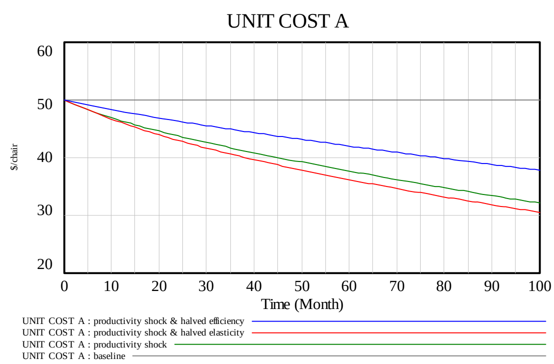


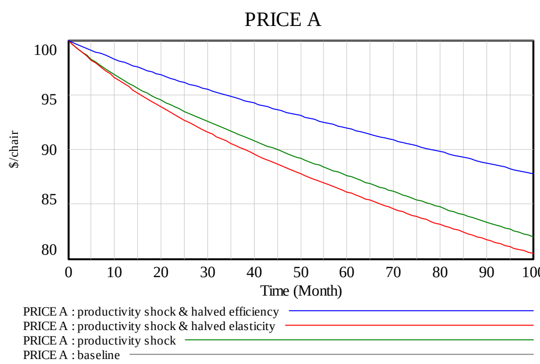
Thus, a reduction in the price of firm A's product leads to a response by company B to reduce its costs, and *vice versa*, as represented by the arrows that cross just to the right of the centre of the diagram. The cost reduction generally requires investment expenditure, which is not included in the present model but can readily be incorporated. The change in price also affects demand, and therefore the proportional mark-up. It is assumed that the volume of each firm's production is set by the demand, with the supply automatically being provided.

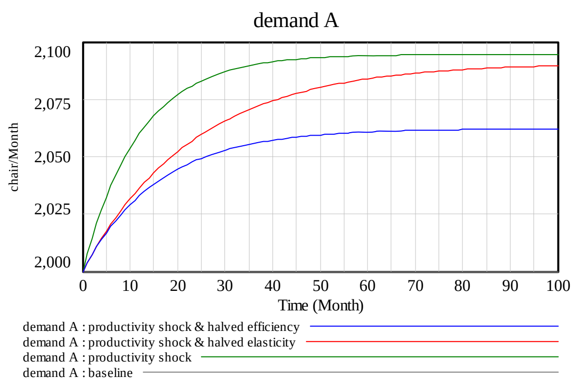
Model behavior

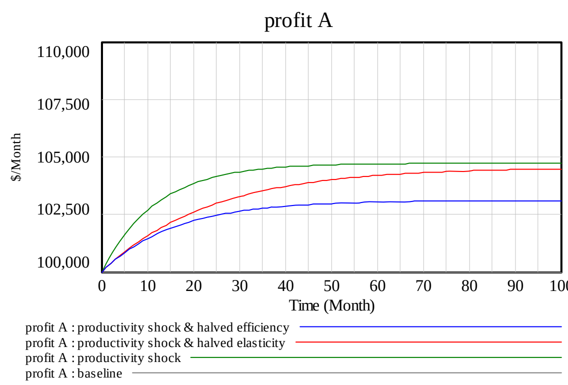
To set the model in motion, a 10 percent productivity shock is introduced by company A, which produces a corresponding fall in unit cost. Propagated effects are then seen in the behavior of the model. This depends on additional features, e.g. the efficiency of investment and the price elasticity of demand. The effects of altering these are investigated by re-running the model with their values having been halved.

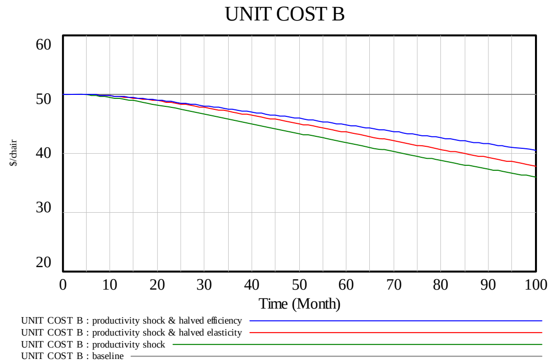
The introduction of the 10 percent productivity shock by firm A is followed by a reduction in its unit cost that continues for the entire 100-month duration of the run (green line), by which time it has reached below 35, a percentage reduction of 35 percent. Firm A's price falls by a similar absolute amount, half in proportional terms. The demand for firm A's product rises to a plateau almost 10 percent above the starting point, and its profit similarly rises to a plateau. Firm B has a similar fall in its unit cost and price, albeit starting slightly later, but its demand and profit are a mirror image of those of firm A. (The supply diagrams are identical to the demand ones and are therefore not shown, in all the simulations.)

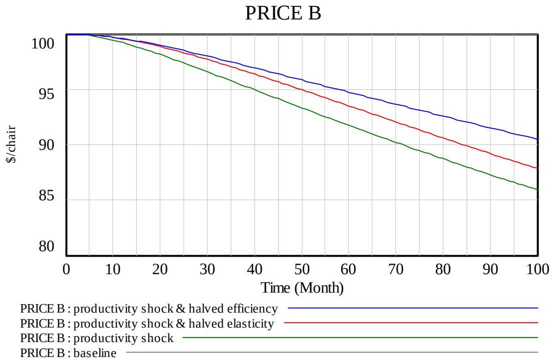


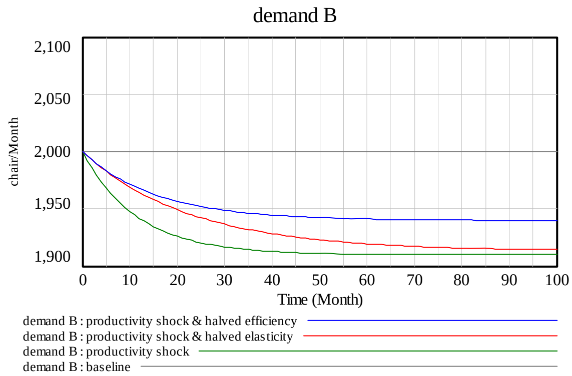


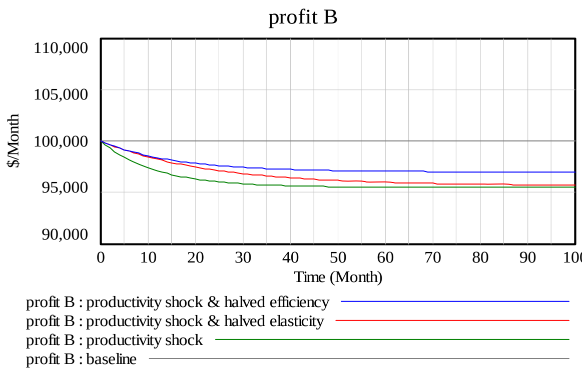








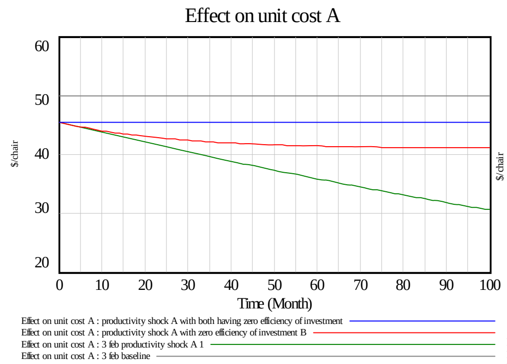


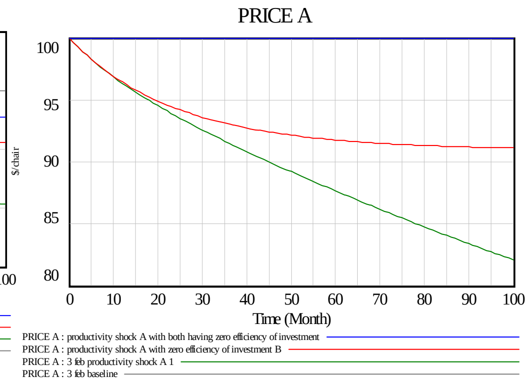


Thus, a state is reached in which both firms are continually changing (reducing) their unit costs and prices, each responding to the threat of the other. The structure of the model guarantees this, except in the special case of the unstable equilibrium where firms have identical levels of productivity (the initial 10 percent productivity shock is merely a device to initiate the dynamic process).

Halving the elasticity (red line) produces a qualitatively similar pattern, with slightly more of a fall in unit cost and price for firm A, but the opposite for firm B. It takes longer to reach the same altered demand and profit for both firms. Halving the efficiency of investment for firm A (blue line) makes all the changes less extreme for both firms, and affects the level but not the timing of the plateau effect.

This pattern depends on firms having not only the incentive but also the ability to reduce their unit costs. If this ability is removed, by setting efficiency of investment to zero, then nothing happens. The simulation (see next page, blue line) is identical to baseline, except that a firm with a 10 percent productivity shock has 10 percent lower costs – but there is no continuing cost- or price-reduction process in either firm. If firm A's efficiency of investment is restored to 1 but that of firm B is kept at zero (red line), A's advantage is shown in its fall in unit cost and price – which is now only temporary – and its rise in demand and market share. Firm B has no continuing change in unit cost or price, and correspondingly loses demand and market share.


Effect on unit cost A
$/chair
Time (Month)
Effect on unit cost A : productivity shock A with both having zero efficiency of investment
Effect on unit cost A : productivity shock A with zero efficiency of investment B
Effect on unit cost A : 3 feb productivity shock A 1
Effect on unit cost A : 3 feb baseline


PRICE A
$/chair
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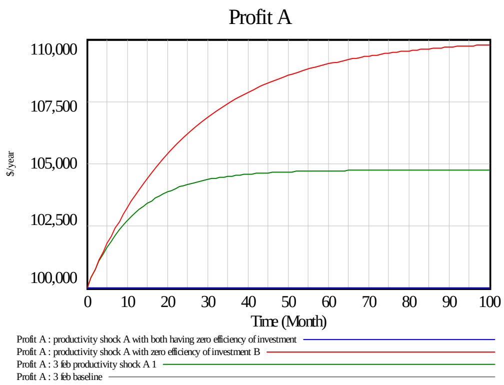
Profit A
$/year
Time (Month)
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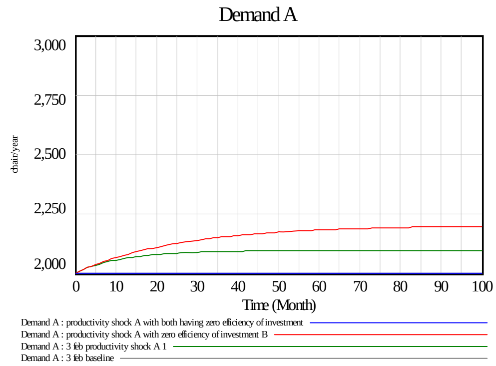
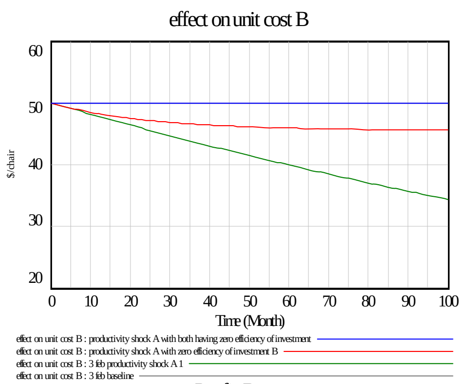
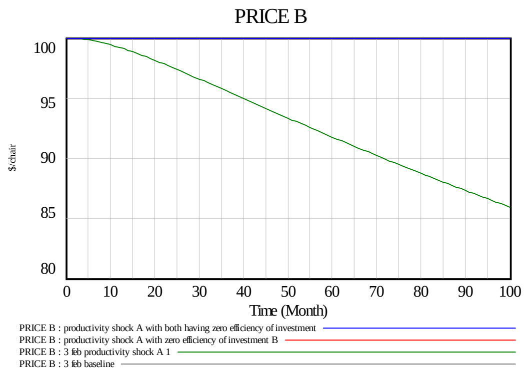
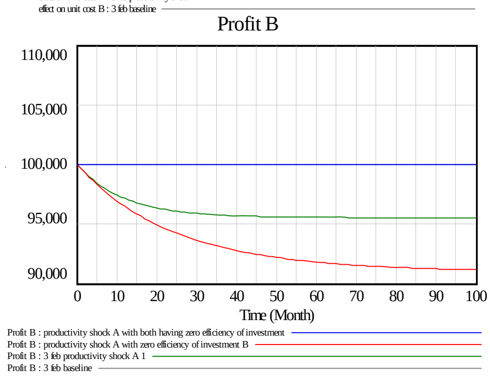
Profit A : productivity shock A with zero efficiency of investment B
Profit A : 3 feb productivity shock A 1
Profit A : 3 feb baseline


Demand A
chair/year
Time (Month)
Demand A : productivity shock A with both having zero efficiency of investment
Demand A : productivity shock A with zero efficiency of investment B
Demand A : 3 feb productivity shock A 1
Demand A : 3 feb baseline


effect on unit cost B
$/chair
Time (Month)
effect on unit cost B : productivity shock A with both having zero efficiency of investment
effect on unit cost B : productivity shock A with zero efficiency of investment B
effect on unit cost B : 3 feb productivity shock A 1
effect on unit cost B : 3 feb baseline


PRICE B
$/chair
Time (Month)
PRICE B : productivity shock A with both having zero efficiency of investment
PRICE B : productivity shock A with zero efficiency of investment B
PRICE B : 3 feb productivity shock A 1
PRICE B : 3 feb baseline


Profit B
Time (Month)
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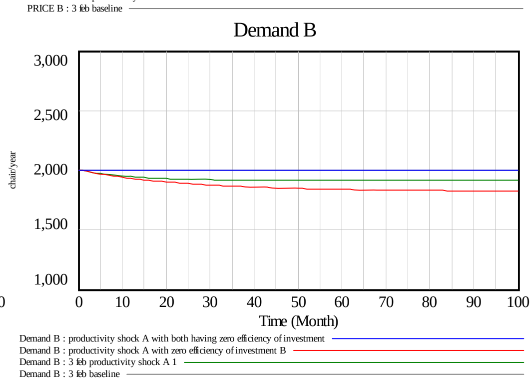
Demand B
chair/year
Time (Month)
Demand B : productivity shock A with both having zero efficiency of investment
Demand B : productivity shock A with zero efficiency of investment B
Demand B : 3 feb productivity shock A 1
Demand B : 3 feb baseline

Additional changes to the model similarly lead to alterations in the precise movement of the variables, but without altering the overall pattern. For example, the value of baseline profit and of previous supply for each firm can be altered, making the firms less similar. As long as the values of efficiency of investment are strictly positive for both firms, the model generates a fall in the unit cost and price of both firms that is still continuing after 100 months.

Discussion

Model behavior, and its economic consequences

The model has deliberately been kept as simple as possible, in order to show how an arms race in cost-cutting investment between firms can generate a continuing fall in costs. The intention is to generate insight, rather than e.g. achieve prediction (Hirsch, 1984; Epstein, 1997).

The basic dynamic of the model arises from a historical and institutional analysis: it has been argued that the modern type of economic growth, as seen only since the industrial revolution, is a consequence of competition between capitalist real-economy firms (Joffe, 2011). These employ wage labor (Hodgson, 1999), giving them control over the number and type of workers, in contrast with the predominantly family-run firms of the pre-capitalist era; more generally they have a high degree of control over the productive methods. They consequently also have two key types of flexibility: in the size of the market that they can supply and in the combination of inputs that they can bring together. This flexibility allows manipulation of the scale of production as well as of costs. Thus, the ***ability*** of firms to reduce costs by adjusting their workforce and productive methods is the key, not only to their success in competing, but also to the broader consequences for the economy of the arms race that this sets in motion.

The implication of a fall in unit costs over time is that the same output can be produced with a lower input or, if the same quantity of input is maintained, this can generate a higher output. In other words, it is one source of economic growth, that is likely to be especially applicable to the situation of early or low-income capitalism in any particular economy, e.g. England 200 years ago, Taiwan from the 1950s or China more recently. The fall in price accentuates this, giving a second impetus to growth, because by making the product of this sector less expensive it raises the effective buying power of those in other sectors. It has been suggested that this produces a more robust growth pattern than an economy that relies on one sector alone for productivity growth (Joffe, 2011).

The situation where efficiency of investment is set to zero for both firms is reminiscent of the pre-industrial economy, in which technical improvements were frequent but the modern type of exponential growth did not occur: thus, firm A experiences a 10 percent unit cost reduction that follows its productivity shock, but is unable to capitalise on this because it is unable to expand to capture market share from firm B. Economic growth under such conditions results from increasing division of labor, and hence specialization, depending in turn on the extent of the market – “Smithian growth” (Lowe, 1977; Kelly, 1997) – which is far too weak a process to explain the magnitude of modern economic growth (McCloskey, 2010).

The simulation in which only firm B has its efficiency of investment set to zero mimics the unequal competition between a capitalist firm and one that is not able to control its costs, e.g. a family concern. Examples include the historical displacement of sole traders and family firms in sector after sector as capitalist (wage-labor-employing) production gains a foothold in an economy, starting with the destitution of the English handloom weavers in the early 19^{th} century. The process still continues, as small corner shops struggle to compete with supermarkets, chain stores, and now online retailers. The reason that the process shown in these diagrams is time-limited is that there is only one "capitalist" firm, so that effective competition stops. If competition were present, the family firm would continue to be squeezed and could disappear.

Possible future extensions of the model

With the model as currently specified, unit costs and prices would be driven to zero and beyond, which is clearly nonsensical. The situation is analogous to Malthus' model of population growth, which did not incorporate a limited carrying capacity – this was left to Verhulst to develop (Kingsland, 1995). A similar extension to make the limitations to cost reduction explicit could be added to the present model.

The cost of the investment has not been included, but this could readily be done by extending the model to deal also with profit and how it can be ploughed back into trying to ensure the future success of the firm. A further extension could be to incorporate the possibility of borrowing in order to invest. It would likewise be possible to include capital depreciation (as distinct from obsolescence).

Beyond the basic logic of falling costs, the precise dynamics have not yet been explored. These are of secondary importance, but it could be of interest to explore the effect of delay in the process from investment decision to practical implementation, as well as inaccuracy and delay in information processing. Furthermore, the model assumes that each firm responds to prices, which are straightforward to monitor, but in real-life competition it is likely that firms also monitor such things as competitors' costs, investment, possible technologies, etc. Similarly, it would be possible to consider projections of the expected/likely behavior of others. Such factors would be relevant to the degree of instability, e.g. of price series, and to distinguishing leader-follower from leapfrogging behavior.

The model could be extended to encompass more than one sector, with each being the customer and the producer for the other. This would place the focus on the buying power in each, which depends on the wage bill (measured by total costs) in relation to the price level in the other. Further possibilities include the introduction of the financial sector and/or of the state.

In addition to this system dynamics model, other modeling approaches are being used in parallel, to explore the same basic economic concepts. These include simultaneous differential equations, in particular building on Richardson's arms race model (Richardson, 1960), and an agent-based model using NetLogo. The latter complements the system dynamics approach, because it is easier to include a larger number of agents (firms) in such a model, and to vary their characteristics e.g. using random allocation.

Appendix: equations used in the model (the product is called “chair” for concreteness)

change in price A = change in unit cost A * supply demand ratio A		$/(Month*chair)
PRICE A = int (change in price A)	100	$/chair
revenue A = PRICE A * demand A		$/Month
supply demand ratio A = demand A / supply A		Dmnl
profit A = revenue A - costs A		$/Month
supply A = previous supply A * profit A / baseline profit A		chair/Month
previous supply A	1000	chair/Month
baseline profit A	50000	$/Month
change in unit cost A = target change in unit cost A * efficiency of investment A / time to adjust cost A		$/(chair*Month)
UNIT COST A = int (change in unit cost A)	50	$/chair
costs A = UNIT COST A * demand A		$/Month
demand A = reference demand * effect price demand A		chair/Month
effect of price on demand A = EXP(demand elasticity * LN(PRICE A / PRICE B))		Dmnl
productivity shock A	1	Dmnl
effect on unit cost A=UNIT COST A*effect price demand A/productivity shock A		$/chair
target change in unit cost A = effect on unit cost A - UNIT COST A		$/chair
efficiency of investment A	1	Dmnl
time to adjust cost A	12	Month
reference demand	2000	chair/Month
demand elasticity	-1	Dmnl

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