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The Dynamics of the Organisation of Industry

by

Esben Sloth Andersen

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Esben Sloth Andersen
Dept. of Business Studies
Aalborg University
Fibigerstraede 4
9220 Aalborg OE
E-mail: esa@business.auc.dk
WWW: http://www.business.auc.dk/evolution/esa/

Abstract

The paper presents and formalises an approach to the evolution of the organisation of industry which starts from multi-activity firms, and which relates to economists like Young, Stigler, and Richardson. To capture the open-ended process of disintegration of industry, the paper operates with decomposable tasks and gives an account of the vertical and horizontal structure of production by means of weighted trees — in the graph-theoretical sense. Based on this addition to the analytical toolbox, the paper gives an account of the decomposition of industry as driven by the structural innovations and process innovations of firms that specialise and exchange in an open-ended evolutionary process.

Keywords

Vertical disintegration, horizontal disintegration, production trees, specialisation of production, specialisation of R&D, George B. Richardson.

JEL classification

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Contents

1. Introduction

In principle there are two main approaches to the study of the evolution of the organisation of industry — the integration approach and the disintegration approach.

The integration approach starts from single-activity firms, so that all transactions are coordinated by markets. The question is then whether more activities will be integrated into the conscious planning of the firms. Metaphorically, we may ask whether we will see a growth of the tiny islands in the ocean of market relations (cf. Robertson 1930, 85). For such a study the transaction costs approach of Coase (1937) and Williamson (1979) seems to be appropriate, but modern industrial economics offer a large set of additional analytic tools.

The disintegration approach starts from multi-activity firms, each of which plans the relationships between its different activities. The task is to explain why and how individual activities become outsourced and coordinated by more-or-less clear-cut market mechanisms. In principle this disintegration approach may start from totally autarkic firms (consumer-producer firms) like in Adam Smith's (1976, bk. I, ch. 3) story of the Highlands of Scotland where "every farmer must be butcher, baker, and brewer for his own family", and where a more and more complex market system may emerge in a slow and gradual manner due to the increase of the extent of the potential markets. Although there have been a series of attempts to develop a conceptual framework for dealing with this process of disintegration (Young 1928, Stigler 1951, Richardson 1972), it is fair to say that the disintegration approach has not yet developed into a paradigm of research. This situation may, however, begin to change due to the development of a systematic "evolutionary economics" from Nelson and Winter (1982) and onwards.

There are strong arguments for an effort to develop analytical tools that support the disintegration approach. The basic argument is that this approach is clearly an underdeveloped complement to the integration approach. Furthermore, it may be argued that if there is a competition between the two approaches, then the disintegration approach has certain logical and historical advantages over the integration approach. A major logical advantage of the disintegration approach can most easily be seen if we, like Adam Smith, start from autarkic (consumer-producer) firms. As we shall see in the following, these firms may be specified in a way which includes as endogenous most of the variables which will also ultimately characterise the full-blown economic system. On the other hand, the integration approach normally have a specify the process by a large number of exogenous transaction-cost variables. The historical advantages of the disintegration approach might not be so obvious to all, since theoretical perspectives tend to influence the interpretation of the facts of economic history. However, if we e.g. want to explain the trend from simpler to more complex environments of firms, then the disintegration approach has, as we shall see below, several advantages.

The starting point of the present paper is Richardson's (1972) article on "The Organization of Industry" combined with a closely related article that emphasises the process of vertical disintegration (Richardson 1975). Before we embark upon the formalisation of core elements of these articles, it is helpful to sketch a few stories that give a quick intuition about the economic processes that the formalisation relates to (section 2). Then we (in section 3) summarise Richardson's theory of firms and their activities. This theory is then related to a more formalised scheme for analysing the processes of vertical disintegration (section 4) and of horizontal disintegration (section 5). Finally, we sum up some conclusions (section 6).

2. Foundational stories of pins, peasants and printing

The disintegration approach to the evolution of the organisation of industry has clear classical roots while the integration approach is of a more recent neoclassical origin. To find the roots of the disintegration approach, it is important to remember that Adam Smith developed not only develop a theory of economic equilibrium; he also sketched out a theory of economic evolution. The latter theory was phrased in terms of the increased decomposition and productivity of labour due to an increased extent of the market. The perception of Smith's and other theories of the disintegration has to a large extent been influenced by what may be called "foundational stories" that serve to give a quick intuition of the depicted processes.[1]

The fact that Smith offers a theory of the evolution of the organisation of industry as well as of the economy as a whole has often been ignored, not least because it has been seen in relation to a narrow interpretation of his story of the effects of the division of labour within a pin-making firm. According to this famous story (Smith 1976, bk. I, ch. 1)

> the trade of the pin-maker ... is divided into a number of branches, of which the greater part are likewise peculiar trades. One man draws out the wire, another straights it, a third cuts it, a fourth points it, a fifth grinds it at the top for receiving the head; to make the head requires three distinct operations; to put it on is a peculiar business, to whiten the pins is another; it is even a trade by itself to put them into the paper; ... if they had all wrought separately and independently, and without any of them having been educated to this peculiar business, they could certainly not each of them have made twenty, perhaps not one pin in a day; that is, certainly, not the two hundred and fortieth, perhaps not the four thousand eight hundredth part of what they are at present capable of performing, in consequence of a proper division and combination of their different operations.

This story can be interpreted as a comparative-static analysis of an industry with increasing returns to scale. But from Smith's own wording it is obvious that we should rather think of this “very trifling” example of pin-making as a parable of the division of labour that evolves in the economy as a whole. This is obvious when he turns to the more general effects of the interplay between the division of labour in the economy as the whole which goes hand in hand with an increase in the size of the markets.

Smith has two main stories to depict this complex and open-ended process. The first story concerns the horizontal disintegration of the more-or-less autarkic peasant households. Smith (1976, bk. I, ch. 3) writes:

> In lone houses and very small villages which are scattered about in so desert a country as the Highlands of Scotland, every farmer must be butcher, baker, and brewer for his own family. In such situations we can scarce expect to find even a smith, a carpenter, or a mason .... The scattered families ... must learn to perform themselves a great number of little pieces of work, for which, in more populous countries, they would call in the assistance of those workmen.

Here the difference between backward and advanced countries is phrased in terms of transport costs, another fact which may hinder an understanding of the potentials of Smith’s theory of economic and industrial evolution. This peculiar interpretation of the limits to the division of labour is less dominant when we turn to Smith’s (1976, bk. I, ch. 1) second story about the highly complex vertical division of labour in relation to the production of a “woollen coat”. We shall not consider this story, however. In the present context a more focussed Smithian account for the network of vertical relationships is more useful, so we shall instead apply the example emphasised by Young (1928, 537–538): the disintegration of the printing trade.

> The successors of the early printers, it has often been observed, are not only the printers of today, with their own specialized establishments, but also the producers of wood pulp, of various kinds of paper, of inks and their different ingredients, of typemetal and of type, the group of industries concerned with the technical parts of the producing of illustrations and the manufacturers of specialized tools and machines for use in printing and in these various auxiliary industries. The list could be extended, both by enumerating other industries which are directly ancillary to the present printing trades and by going back to industries which, while supplying the industries which supply the printing trades, also supply other industries, concerned with preliminary stages in the making of final products other than printed books and newspapers.

It is obvious that the story of the evolution of the printing business (as well as the story of the disintegration of the peasant household) gives quite different intuitions of the evolution of industry than the story of pin-making. In the following we shall try to formalise these intuitions.

3. Tasks, activities and capabilities of firms

Let us begin with issues relating to the printing industry story (and the woolen coat story) of the vertical division of labour. Here an initial problem is to determine why and how individual firms specialise in some of the interrelated activities. According to Richardson (1975, 355)[2] we should for this purpose, which is closely related to Adam Smith's vision of economic evolution, regard

> firms as undertaking *activities* rather than making and selling products, these activities having to do with the discovery and estimation of future wants, with research, development, and design, with the execution and co-ordination of the processes of physical transformation, with the marketing of goods, and so on. We must then recognize that activities have to be carried out by organizations with appropriate *capabilities*, that is to say with appropriate knowledge, experience, and skills. The capability of an organization may derive, for example, from command of some technology, such as electronics, or some technique of marketing. Activities that require the same capability for their undertaking I shall call *similar* activities. Where activities represent different phases of a process of production that have in one way or another to be co-ordinated, I shall call them *complementary*.

With these notions we observe that (1) the capabilities of an individual firm are limited and not all equally strong in comparison with other firms, (2) the firm will have a comparative advantage in performing similar activities that emphasise its strong capabilities, (3) vertically related activities will in general require different capabilities, including some in which the firm has no particular strength. Thus, we should expect an individual firm to specialise in particular phases of the vertically related activities. This conclusion is strengthened by the fact that activities often exhibit increasing returns.

There are, however, closely complementary activities whose coordination cannot easily be left to standard markets (Richardson 1972, 891) The alternative is not necessarily intrafirm planning. There is also a large set of types of cooperative arrangements between firms that can be applied. The choice between the different arrangements depends on the degree of quantitative and qualitative coordination required by the complementary activities. Richardson (1972, 892) also points out that we should "observe that the organization of industry has to adapt itself to the need for coordination of a rather special kind, for co-ordination, that is to say, between the development of technology and its exploitation."

Given this analysis of the role of similar and complementary activities in the organisation of industry, we can turn to the question whether the process of specialisation will "at the end of the road" reach a general equilibrium with monopolistic competition of the type depicted by Chamberlin (1962). Richardson's (1975, 357) answer is "that the end of the road may never be reached. ... For just as one set of activities was separable into a number of components, so each of these in turn become the field for a further division of labour." The opening up of these possibilities are part of the evolutionary process itself: "the very process of adaption, by increasing productivity and therefore market size, ensures that the adaptation is no longer appropriate to the opportunities it has itself created." (Richardson 1975, 358)

This "theory of unending development" (Richardson 1975, 358) presuppose that any activity can be decomposed into subactivities. This process of decomposition is easier to understand if each given activity is assumed to fulfil a particular *task*, a concept that relates to the theory of problem solving (cf. e.g. Simon 1981). The task can be considered as a demand specification which only concerns the output of the activity. The methods, and thus the productivity, by which the task is solved is open to change.[3] One of these possible changes is the decomposition of the task into subtasks by means of the method of step-wise refinement — like in structured computer programming (see Dahl et al. 1972). Thus the task of producing a single pin may by an artisan be considered as an undivided task, but the task of producing a very large number of pins in the Smithian example may be considered as consisting of about 18 subtasks, each solved by a particular activity of workers with adequate capabilities.[4] Later the task structure has changed a lot, mainly because of the use of integrated machine solutions to the task of pin-making which means that the most important tasks have been transferred to the machine industry (see Pratten 1980).

The open-ended definition of tasks becomes especially important when we in this way turn from intrafirm to interfirm division of labour. To the consumer the important thing is the price and quality of a consumption good, and not (normally[5]) the methods by which it is produced. This means that the producer is free to decide how the task is to be solved, to what degree the task is to be subdivided, and whether some of the subtasks should be solved by other firms (which in turn may outsource subsubtasks). These decisions are typically subject to a life cycle of major tasks as well as of firms and of industries. The elements of a theory of this kind of life cycles are available in the papers of Young (1928), Stigler (1951), and Richardson (1975), as well as in some of the papers on the product life cycle (starting from Vernon 1966).

The most important assumptions in this kind of theory of life cycles are that (1) the splitting up of tasks are first performed within a firm as it encounters an increasing demand, (2) the specification of new subtasks are in the beginning idiosyncratic and changing, and (3) the sizes of the activities related to the subtasks are in the beginning too small to allow for the investments necessary to develop the task specifications and in other ways to reduce transaction costs. Therefore, we see an initial process of integration measured by the number of activities performed by the firm. However, this is only a first step which — with a time lag — is followed by an outsourcing of many of the new activities. Since the in-house division of labour is difficult to study and measure, the main impression is often that a firm and an industry whose primary output is growing is characterised by a vertical disintegration. Later when output stagnates or decreases, there may be seen a process of vertical integration in order to secure employment and/or to control the costs of the inputs. Thus, the development fits the Young--Stigler hypothesis "that vertical disintegration is the typical development in growing industries, vertical integration in declining industries." (Stigler 1951) But alternative life cycles may also be encountered if one makes an account of both in-house activities and market transactions (see e.g. Langlois and Robertson 1995).

From the above accounts it is clear that Richardson and other proponents of the disintegration approach suggests a very rich agenda for research which might be enhanced by the task concept. However, such an approach and the related "theories of industrial organization ... should not try to do too much." (Richardson 1972, 896) This problem seems even to be inherent in Richardson's own work: the backbones of the disintegration approach have not been made clear before interest turns to very complex issues of e.g. interfirm coordination. In the present paper we shall try to develop some of these backbones, including a theory of the role of intrafirm coordination between the closely complementary activities of R&D and production that exploits innovative results. The purpose is not to minimise the importance of interfirm cooperation but to develop a clear-cut framework that can be considered as a simplistic first approximation to the analysis of the evolution of the organisation of industry. The next step is to analyse the co-evolution of firms (and other organisations) engaged in closely complementary activities (see e.g. Nelson 1994, Andersen and Lundvall 1997).

4. A vertical scheme of analysis

Since the above analysis of the stories of pins and printing deals with a very complex process, there is an obvious need for a more formalised treatment. In the following an attempt of such a formalisation of vertical disintegration will be sketched out in relation to post-Schumpeterian "evolutionary economics" in the tradition of Nelson and Winter (1982).[6] But since the analysis of "Schumpeterian competition" within this tradition has not hitherto dealt with the problems of disintegration and "economic complexity", there is no ready-made solution. The major change we shall make in the post-Schumpeterian models is to move the attention away from the problems of capital formation by assuming that labour is the sole factor of production. We shall instead emphasise the problem of the creation and exploitation of competencies through R&D and specialisation. In other words, we put the complementary activities of specialised R&D and specialised production at the centre of an analysis of the evolution of firms and of industry. At first we emphasise vertical disintegration; later (in section 5) we turn to fundamental issues of horizontal disintegration.

4.1. Consumers and firms

In the analysis of vertical disintegration we start from a system of firms that produces a single homogeneous consumption product (product no 1); we may think of e.g. standardised pins or printed text of a standardised format. The aggregate output in period t is $Q_{1,t}$. The demand for this final output can be specified in several ways, but it is most easy to assume — with Nelson and Winter (1982, chs. 12-14)— that we have a unitary elasticity of demand with respect to price, i.e. the aggregate of consumers spends a fixed amount of money, M. Thus, $p_{1,t} = M/Q_{1,t}$. We might also consider other specifications of demand and their influence on industrial evolution.

To simplify, the model operates with a fixed number of firms, m $(1, \ldots, j, \ldots, m)$. Each of these firms are endowed with a fixed and unchanging labour force.[7] The labour force of each firm supplies it with a fixed amount of labour, L, at a fixed and uniform wage rate, w. Thus, the decision problem of firms is to attempt to maximise profits given fixed labour costs of wL.

Labour can be used for an indefinite number of production activities as well as for R&D (the latter will be dealt with in section 4.5). The R&D intensity of firm is $r_{j,t}$, so the amount of labour available for production is $\left(1-r_{j,t}\right)L$.

4.2. The vertical structure of production

All production activities are defined by a task, i.e. a specification of a unit of the type of output of that fulfils the task. The activity which delivers a unit of a particular type of output is performed by labour in combination with the results of zero, one or two subtasks. If the results of one subtask is applied in the production of one unit of output of a task, there is always a need of one unit of output of the subtask. Similarly, one unit of each of two subtasks may be used. Thus the units of intermediate products are — directly or indirectly — defined by the units of the final consumer product.

If this definition of the process of production is applied recursively, the result is a structure which may be called a production tree (cf. Andersen 1996). This is a graph theoretical structure that is defined by a set of “nodes” (activities) and a set of “branches” each of which connects two activities. The tree is organised since there is only one “root” activity (the household consumption of product no 1). The tree ends with “leaves”, i.e. primitive activities for which there are no subtasks. An example of such a production tree is depicted in figure 1.

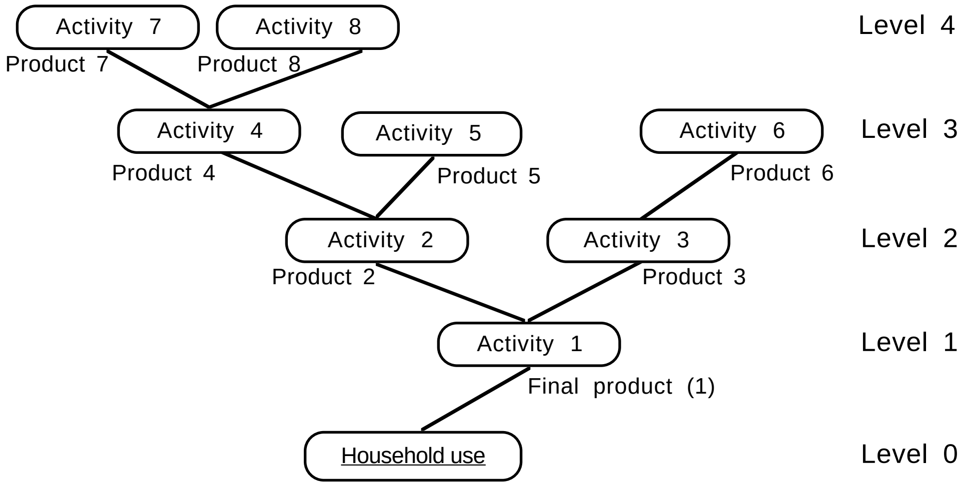

Figure 1. An example of a production tree

In the figure there is a root node ("household use", node no 0) as well as 8 production activity nodes that supply products 1, ..., i, ..., $n_{j,t}$, where $n_{j,t} = 8$. The graph of the production tree is a binary tree since each node has at most one downgoing[8] and two upgoing branches. Such a binary tree represents the simplest non-linear production structure, and it is obviously serving graphical and computational convenience rather than economic realism.[9] However, the binary tree represents a clear-cut decomposition of the production of a final good. Furthermore, this decomposition is open-ended since at any point of time an activity which is served by the results of zero or one subtasks can be decomposed. Thus the primitive activities (5, 6, 7, and 8) in figure 1 can be split into one modified activity assisted by the intermediate products delivered by one or two activities. Also activity 3 is open to further decomposition since it is only assisted by one subactivity.

4.3. Productivities and costs

To analyse how firms specialise with respect to their production trees, we need an account for their competencies and how these competencies evolve over time. To start with, it is assumed that each firm has a specific labour productivity for each good, and these productivities are independent of the size of production. This simplifying assumption implies e.g. that an employee which is moved from one activity to another is able to produce with the firm's general level of capability. The constant returns are, however, only related to the scale of production. In the R&D activities of firms there are increasing returns to scale because the costs of an innovation is independent upon its scale of application (see section 4.5).

The competencies of each firm determine how the nodes and the branches of its production tree are weighted. Nodes are weighted by the quantity of labour needed by the firm for producing one unit of the output of the activity. This means that $a_{i,j,t}$ units of labour are necessary in period *t* for firm *j*'s production of one unit of product i. Branches are weighted by the "quality" of the product, $b_{i,j,t}$, i.e. by the quantity of the intermediate product needed by the receiving node for producing one unit of its output. In the simplest case — and in this paper — the weights of all branches are 1, i.e. one unit of each of the intermediate products in the tree is needed for producing one unit of final output.

Given this weighting of a firm's production tree (including the assumption that $b_{i,j,t} = 1$ for all *i*'s and *j*'s), it is for the case of in-house production of all intermediate products easy to calculate the unit labour requirements of the firm's production of the final product, $A_{1,j,t}$. The reason is that in this case we can ignore the non-linear structure of production and simply add the labour requirements of each of the subactivities:

$$A_{i,j,t} = \sum_{i=1}^{n_{j,t}} a_{i,j,t}$$

The firm's unit labour costs are then $wA_{1,j,t}$ and its total output is is determined by its total amount of labour minus its labour used for R&D, i.e. $\left(1 - r_{j,t}\right) L / A_{1,j,t}$ (given that $p_{1,t-1} \geq wA_{1,j,t}$). Similarly, the firm can calculate its labour costs for any given subtree. For instance, the labour costs of producing one unit of product 4 of figure 1 is the sum of the labour requirements for activity 4, 7, and 8 times the wage rate (plus some correction for R&D expenses).

4.4. Exchange of intermediate products

Firms may engage in exchange of intermediate products, but only if they differ with respect to their productivities in the different parts of their production trees. If they were all alike, there would be no advantage in specialising (due to the constant returns to scale in production). But even minor productivity differentials might not be enough for motivating firms are to engage in exchange. The reason is that our analytical scheme includes a simple form of transaction costs.

In the present context we shall interpret transaction costs as the gap between the quantity that the seller supplies and the quantity that the buyer receives (or perceive to receive). If firm *j* delivers product i in the quantity $Q_{i,j,t}$, then the receiver act as if it has only got $k_{i,j,t} Q_{i,j,t}$, where $0 \leq k_{i,j,t} \leq 1$. The simplest interpretation of this gap[10] is that it represents the amount of the good that disappears or is delivered in an unusable form. But other interpretations are possible. For instance, we may consider the case where the delivered product is not an exact copy of the in-house product, so that some extra production costs are imposed on the buyer. These types of transaction costs are likely to change over time, for instance in proportion to the cumulated quantity of exchange of the product.[11]

Exchange is most easily organised through contracts related to order production. Potential sellers post in the beginning of each period an offer to the market place specifying product and price. Given all offers, potential buyers can then decide which activities they want to outsource and which activities they want to perform in house. Two kinds of considerations are taken into account in this decision. First, firms want to use fully their given amount of labour, L. Second, they want to do this as profitable as possible. If a firm thinks that it is not constrained by insufficient demand for its market output, and if there are not special considerations with respect to instability or R&D (see section 4.5), then it wants to outsource all activities of any subtree which outputs a product *i* for which the (transaction-cost corrected) market price is less than its labour costs (see section 4.3).

Then comes the actual contracting and deliveries between firms. Here we shall assume that there is no storage of products. Thus, a potential seller cannot in period \$t\$ accept more contracts than it can fulfil with its given productivities and its given quantity of labour. However, the seller has in a given period to stick to the price it has already posted to the marketplace. To simplify, we shall also assume that the intermediate products are delivered soon enough to allow the receiver to produce its output in the same period (and so on recursively down the production trees). At the end the firms calculate their profits and they also have some information about their relative performance.[12]

The outcome of the exchange between firms with a variety of capabilities is the emergence of a vertical division of labour. Figure 2 shows one step in the process of vertical disintegration. In this case we have assumed that one type of firm has specialised in delivering the final output. If only buys one intermediate product (no 2), so it has to perform for itself activities 1, 3, and 5. Another type of firm sells product no 2 and buys product no 7. A third type of firm sells product no 7 and buy no inputs.

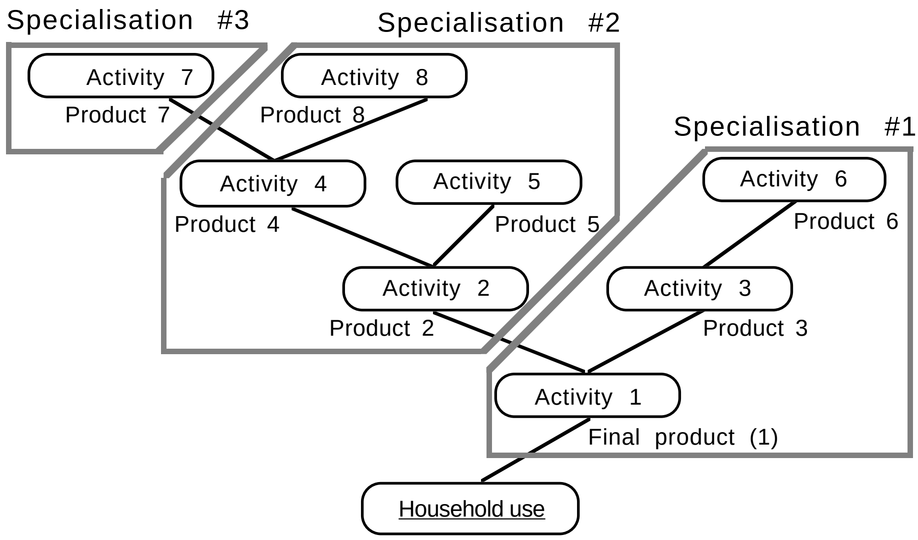

Figure 2. An example of simple interfirm division of labour

Figure 2 covers the very simple case in which all the firms that sell a particular product perform the same set of activities and buy the same inputs. This is not the normal case. For instance, although the pattern depicted in figure 2 may be the most widespread in an industrial sector, there may still be one firm that performs an in-house production of all the 8 production activities related to the final output. Firms may also show different depths of their production trees. For instance, one firm may produce product no 7 as a primitive activity while another firm may have developed a complex in-house division of labour connected to the same output.

4.5. R&D activities and their specialisation

As it has already been pointed out, each firm has in each period a specific labour productivity for each activity in its production tree. The firm's set of labour requirements reflects its private set of production algorithms. For a given product *i* there is either a primitive algorithm which is described in terms of labour alone (an algorithm for one of the "leaves" of the production tree) or a decomposed algorithm that is described as a combination of labour and one or two intermediate products (for the internal nodes of the production tree).

The algorithms can be improved by innovations which are the outcome of the firm's R&D activities. The effects of an innovation in period *t* can be fully exploited in period $t+1$. There are two types of innovation: simple process innovations and structural innovations. A simple process innovation diminishes the labour requirements of an individual activity within a given production tree, i.e. if firm *j* innovates with respect to activity *i*, then $a_{i,j,t+1} < a_{i,j,t}$. A structural innovation means that a production activity with zero or one intermediate input is decomposed into two activities of which one delivers an input to the second activity. A structural innovation is initially considered to be cost neutral, i.e. that the sum of the labour requirements of the decomposed activities is equal to the previous labour requirements of the undivided activity. However, later process innovations can concern the subactivities individually.

As a result of the firm's R&D work in period t, one or more innovations may take place. Whether an innovation will actually take place is determined in five steps.[13] First, we find out how many (if any) innovations that is obtained by the firm in period t. This is a probability function of its R&D intensity, $r_{j,t}$, or rather of the resulting R&D effort. Second, we see which of the activities are subject to innovation. This is determined probabilistically by means of the "focusing function" that reflects the way the firm specialises its R&D work. Third, we determine for activities with potential new subtasks whether a simple process innovation or a structural innovation will take place. Fourth, we find the innovative result. For structural innovations this is quite simple. For process innovations we find a new labour requirement. Normally it is assumed that technological development is cumulative so that we find the (log of the) new productivity in a probability distribution which has the (log of the) existing productivity as its mean. But it is also possible to define technological progress functions with spill-overs between intrafirm activities, between firms and even with with an exogenous, science-based mean. Fifth, the firm implements the new productivity in the next period if it is a structural innovation or if is better that the previous labour requirement (i.e. if $a_{i,j,t+1} < a_{i,j,t}$).

From the above account it is clear that the firm's decision-making about R&D consists of three parts: First, the firm has to determine how large a part of its labour should be devoted to R&D. To simplify, any increase in this part of the labour force is assumed to immediately obtain average productivity in the production of innovations. Given this simplification, it is easy to change the R&D intensity according to the character of innovative race with other firms. Second, the firm has to determine the relative emphasis on simple innovations and structural innovations. This decision is determined by the niche the firm has found in the production tree as well as by the chances of developing a new speciality high up in the production tree. Third, the firm has to determine a "focussing strategy", i.e. a strategy of how to focus the attention of R&D work to the different parts of the production tree. The (boundedly) optimal strategy in a state of autarky is, in the main, to focus attention in proportion to the amount of labour spend on a particular activity. When exchange of intermediate products is introduced, this strategy can also be applied. But with highly developed exchange, firms come to focus on improving production of a smaller range of activities. If such a focus has been followed for a long time, the relative performance of the firm with respect to other goods is very weak. This means that if other firms take over the market for the firm’s chosen output product, the specialised firm will confront a major set-back in its profits. There are several ways to insure against such a catastrophe.

4.6. The vertical evolution of industry

The existence of a well-developed vertical division of labour in industry is not an automatic outcome of the evolutionary process. It depends on the introduction of different stabilisers which make it profitable to specialise capabilities as well as activities. At the same time the system must delimit transaction costs so that the beneficial effects of vertical disintegration can be obtained.

These and related issues demonstrate that the above vertical scheme of analysis suggests new tasks for the study of an industrial dynamics. In the standard post-Schumpeterian model and many other types of model the firms compete about exactly the same “niche” so that it is difficult to avoid the general dominance of one or a few firms. In order to understand the long-term coexistence of radically different types of economic behaviour, we have — as pointed out by e.g. Young, Stigler and Richardson — to transcend this limited type of model. The introduction of a number of different productive tasks that can be innovated individually creates a multi-dimensional system of competition, which allows the survival of a larger number of behavioural variants. The reason is that firms can specialise: when a firm has made an innovation with respect to one of its activities, it decides whether or not to specialise in a way which emphasises this activity. If it does so, it exploits the innovation on a larger scale. However, it has a problem of creating a market for the intermediate product which is the output of its innovated activity.

The importance of the vertical model is not least based on the fact that it combines the classical approach to the division of labour with the Schumpeterian notion of discontinuous innovation. The model demonstrates how specialisation and innovation are closely connected. At the micro-level vertical specialisation is a way in which a previously unspecialised firm can often increase the returns from its innovation. At a more aggregate level specialisation can be demonstrated to be a way of increasing the speed of the diffusion of the innovation. But the most interesting result of the repeated process of specialisation is the emergence of a complex interindustrial system with new “species” or “industries”.

5. A horizontal scheme of analysis

The analytical scheme sketched out in section 4 has one-sidedly emphasised vertical structures. Thus it has served to develop the intuition suggested by the foundational stories of printing and coat-making at the expense of the story of the peasants of the Highlands (see section 2). Therefore, we shall consider an alternative horizontal scheme of analysis. This scheme tries to formalise some of Richardson's (1972, 1996) ideas of the horizontal specialisation of firms. Like Smith's story the horizontal scheme depicts the initial stages of an economy that undergoes both growth and development (i.e. structural transformation and diversification). Therefore it is a certain sense the scheme is closer to subjects of endogenous growth theory and evolutionary growth theory (cf. Barro and Sala-i-Martin 1995, Silverberg and Verspagen 1997, Nelson 1997) than to the standard study of industrial organisation.

5.1. Consumer-producer firms

Like in Smith's account for economic life in the Highlands we shall start from "consumer-producer firms" or "household firms" that organise the production and consumption of their fixed labour force. To expand intuition about such consumer-producer firms from the standard consumer-producer households of the peasant and artisan type, the reader may also think of firms in an economic system where very-long-term labour contracts have come to dominate, but there are several alternative interpretations. Another possibility is that our "firms" are consumer-producer cooperatives. It is even possible to interpret a consumer-producer firm as a country and thus explicitly to relate to the classical theory of international specialisation; but this country-oriented interpretation misses some of the insights of how an economic system may be created from scratch through an innovation-driven process.

The "employees" of a firm are also its owners (with equal shares). They do not get any standardised wage rate. On the contrary, their consumption is provided for by goods obtained by the firm, either directly through production or indirectly through bilateral exchange. The sole purpose of a consumer-producer firm is to maximise the utility of its employee-owners.

5.2. Consumption and utility

Consumption may include any of an open-ended array of goods. For each good there is a maximum level of per capita consumption. Goods are placed in a hierarchy so that consumers prefer to consume a lower-level good up to its maximum before a higher-level good is consumed. The goods are identified by an ordered, open-ended set of index numbers 1, 2, ..., i, ..., and the index numbers of goods reflects their place in the consumption hierarchy.

If there are no "holes" in the sequence of consumed goods, the utility index, $G_{j,t}$, is simply the number of goods consumed up to their maximum. If e.g. $G_{j,t} = 5.6$, it means that the employee-owners of firm *j* in period *t* have maximum consumption of the first 5 goods while they consume 60% of the maximum of the 6th good. Goods that — due to decision-making problems in a complex market system — come after a "holes" in the ordinary sequence of consumption increase the utility index less that goods consumed in their hierarchical order.

5.3. The horizontal structure of production

The economy is — like in section 4 — endowed with only one factor of production, labour, which is provided by the "employees". There is a fixed number of employees, and each of them supplies a fixed amount of labour. There is no labour market, so employees are distributed permanently between the *m* firms.

Labour can be used to produce any of the goods in the consumption hierarchy as well as for R&D. Production takes the form of a very simple production tree with one root (household use) to which is connected an indefinite number of production activities. We may — as shown by figure 3 — talk of a "production bush". This simple structure is, however, chosen for convenience: if demand is lange enough each of the simple branches may evolve into a full production tree like the one depicted in figure 1.

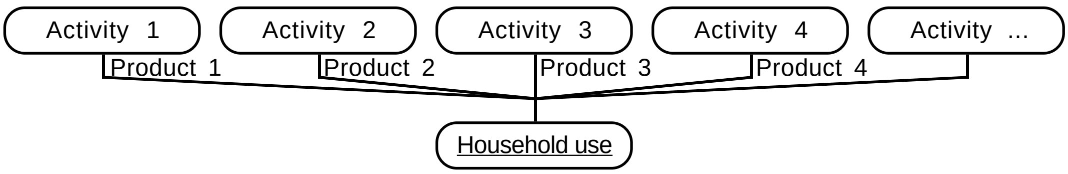

Figure 3. An example of a production "bush"

Each firm has a specific unit labour requirement for each good, and the requirements are independent of the size of production. If firm *j* spends $a_{i,j,t}$ units of labour on good i, it produces one unit this good. If it spends $L_{i,j,t}$ units of labour, it produces $Q_{i,j,t} = L_{i,j,t}/a_{i,j,t}$. The firm *j*'s open-ended list of labour requirements ($a_{1,j,t}$, ..., $a_{i,j,t}$, ...) reflects its private set of production algorithms. These algorithms can be improved by R&D. Algorithms that has not been improved beyond the basic level of knowledge have high unit labour costs.

5.4. Bilateral exchange

Firms may engage in bilateral exchange and thus exploit comparative advantages. But there is a minimum level of productivity differentials that is necessary if firms are to engage in exchange. The reason is that there are transaction costs. These costs mean that the receiving firm obtains only a fraction of the quantity delivered by the supplying firm.

Other constraints are that stocks of goods cannot be stored from one period to the next and that a firm cannot be both a buyer and a seller of the same good.

Exchange is organised through contracts related to order production. The market process runs successively through the hierarchy of goods, starting with good 1. For each good i, firms enters one by one according to their relative performance. When its turn comes, a firm tries to make as many profitable contracts as possible with itself as the supplier of good i. It starts by asking for trade partners that can supply it with its weakest-productivity good, k. The potential trading partners enter according to their relative performance with respect to good k. If an exchange is possible and profitable for both parties, a contract is made. The exchange rate between the two goods depends on the relative productive strength of the two parties.

The assumed organisation of exchange — without a system of money and prices — is designed for experimental economies with relatively few firms and goods. From a computational point of view such an economy is very inefficient. This is demonstrated by the strong assumptions that are needed in order to avoid that simulation time increases exponentially with the number of firms. But the bilateral-exchange system has many advantages in relation to the bottom-up construction of a simple economic system.

5.5. R&D strategies

Each firm has an R&D intensity rule that tells it in each period to spend a certain fraction of its labour on R&D. As a result of the firm's R&D work in period t, a better algorithm for activity i may be found. Whether an innovation will actually take place is determined in five steps — more or less like in section 4.5. The only major difference is that we have changed the concept of a structural innovation. In the present context a structural innovation means the introduction of a new consumption good. Since we shall assume that a new good is initially produced with primitive, standard techniques, the structural innovation concerns the finding of an appropriate product design. Once this product design is found, it is kept unchanged for the rest of the evolutionary process. But this assumption is just made for convenience. It is not difficult to attach a quality indicator, $b_{i,j,t}$, to the product and then to innovate this indicator in the same way as the unit labour requirements are innovated.

From a macroscopic viewpoint the issue of an adequate "focusing strategy" is even more important in the case of horizontal specialisation than in the case of vertical specialisation: the inability to find a product design for the next good in the hierarchy of goods can effectively block growth in the model.

5.6. The innovation-based horizontal evolution of industry

In the horizontal as in the vertical scheme of analysis it is obvious that exchange between firms will only take place if two conditions are fulfilled: firms must differ with respect to productivity, and these differences must be sufficiently large to overcome the costs of transactions between firms. Since transaction costs are likely to be large in the exchange of a good that has not been exchanged before, the core question is how the correspondingly large productivity differentials come about. The present answer is: through innovation.

Innovative activity can be organised in different ways, but it is both realistic and convenient to start from the most simple form of “focussing strategy”: innovating by doing. In this case we consider innovative activity to be an integrated aspect of production. We may also say that R&D activities are spread across the different productive activities according to their quantities of productive labour. This innovative aspect means that the production of a certain good leads to two results: a certain quantity of the good and a (small) probability of obtaining a new algorithm of production.

This version of innovating by doing excludes Arrow’s (1962) learning by doing. The problem is that once a new algorithm is introduced, it cannot be improved gradually by learning; it can only be replaced by another new algorithm. This means that the evolution of production technology is discontinuous: a given productivity level is fixed until it makes a jump due to the introduction of an innovation. However, this does not mean that production learning is not taking place. On the contrary, production learning reveals many problems, faults, limitations and bottle-necks. The new algorithm represents a (partial) solution to these problems. It inherits many aspects of the old algorithm, and it is thus not a totally new technological paradigm. Learning by doing is a limit case where the improvements in the old algorithm take the form of arbitrarily small increments. Innovating by doing takes into account that the process of change is uncertain and may include an element of creative destruction.

There are strong limitations to innovating by producing. The most obvious is that (R&D) workers will not find an algorithm that concerns a production activity that the firm is not performing. Seen from the viewpoint of the consumer-producer firm the problem is that innovations only diminish unit labour requirements with respect to a given range of goods. Even in the case of autarkic firms, this is problematic since structural innovations (the introduction of new goods) cannot take place in this way. Since there is a maximum level of consumption for each good, the growth of the standard of living will sooner or later come to a halt. If productivity continues to increase, this will lead to a reduction in the employment of labour in a forced way, and thus to “technological unemployment” (see Pasinetti 1981, 1993). Such an “unemployment” will, however, suggest a change in the firm's focussing strategy in the same way as Penrose's (1959) managers turns to new tasks when they are freed for old tasks. In the case of consumer-producer firms the "technological unemployment" suggests a more formalised R&D activity with some autonomy *vis-à-vis* productive activities. This allows for a more steady and rapid growth of the standard of living.

Sooner or later the autarkic firms will — for random reasons and/or due to a planned effort — develop productivity differentials which are large enough to allow for profitable exchange (even though transaction costs are very large). From this point of time the conditions for the R&D activities change radically, and a further focussing of innovative activities will take place. We have already discussed this issue in relation to the vertical scheme of analysis (sections 4.5 and 4.6). But it is obvious that it is possible to supplement the notion of innovating by producing with the notion of innovating by exchanging. The idea is that the outcome of exchange-related activities is not only the actual transactions but also new algorithms that serve to reduce transaction costs. Since we have no explicit treatment of exchange-related work in the present paper, it shall simply be assumed that it is proportional to the employment in the production of goods for exchange between firms.

The evolution of a system of autarkic consumer-producer firms is slow because of the relative inefficiency of innovating by producing while an economic system with exchange between firms shows a much more rapid and complex structural economic dynamics. In the study of these patterns computer simulation can be of great help. Some general conclusions can, however, be drawn, even from the present specification of the scheme. Assume that due to random events with respect to innovation, exchange is introduced in a certain period. Since there has been no learning about the problems of exchange, transaction costs are very high for all goods. This means that there are only few cases in which the comparative advantage in the exchange between two firms is sufficient to compensate for the difference between the quantity produced by the delivering party and the quantity consumed by the receiving party. However, if there is some exchange taking place, transaction costs start also decrease and ultimately a "take-off" into an exchange-based economy will probably take place. When this has happened, the structural dynamics will become much quicker. The reason is that the results of the R&D activities are much more effectively applied when firms are allowed to specialise and thereby to exploit the increasing returns in the application of innovations.

6. Summary and conclusions

The above schemes for the analysis of vertical disintegration (section 4) and horizontal disintegration (section 5) have applied a radical version of the capabilities approach to the theory of the firm and to broader issues of industrial organisation. In this account capabilities and their improvement are nearly the sole factors that determine the process of specialisation and output growth. But although capabilities have been put into the centre of analysis, there has been little room for exploring some of the issues covered by the "foundational stories" of pins, peasants, and printing (section 2) and especially some of the insights of the contributors to the disintegration approach (section 3). We shall shortly discuss what the paper has obtained and what is left for further analysis.

The main task of the paper has been to define the vertical and horizontal structure of production in a way that allows for an open-ended decomposition and specialisation of industrial activities. For this purpose the concepts of tasks and trees were proposed.

The first conceptual issue relates to the wide-spread tendency of the activity concept to a given decomposition of production. For the purpose of studying a progressive decomposition of production, the concept of task was suggested. This concept clearly relates to the theory of problem solving (see e.g. Simon 1981). Within this theory a task is a clearly defined problem to be solved. In the theory of production the problem can be defined as producing a clearly defined product. How this problem is left to the firm considered as a problem solver. The task can either be solved in one round of productive activity or decomposed into two or more subtasks — each of which is open to further decomposition. To introduce this view of productive activities was a major purpose of the paper.

To implement the task concept the use of a simple form of graph theory was suggested: production is considered as having the structure of an algorithmically defined tree. In vertical analysis it can conveniently be defined as a binary tree (or an *n*-ary tree) with a root in the single final output of the industrial sector under consideration and with a branching that gives the tree an indefinite height; in horizontal analysis all branches of the tree relates to final consumption and this type of tree has an indefinite width. Such a definition of open-ended trees presuppose the concept of structural innovations that construct the trees successively in a bottom-up manner is crucial.

In order to characterise the productive capabilities of each firm, each activity of the firm's production tree is labelled with the corresponding unit labour requirement (given that one unit of each of the necessary inputs are available). If in the vertical scheme the firm chooses an intermediate product as its market output, it can calculate its unit labour costs be adding the costs of each of the activities in the subtree defined by its market product. If the firm buys some inputs, it saves the corresponding labour costs. This gives the possibility for a large number of different specialisations, even for firms that sells the same product. In the horizontal scheme the possibilities of specialisation are much simpler, but if the horizontal and the vertical approaches are integrated into a single scheme, we have a production structure with a very rich set of specialisation possibilities.

In both the vertical and the horizontal scheme it is the differences between the labelled production trees of the different firms that gives the possibility of interfirm division of labour and exchange. These differences are partly the result of the firms' drifting away from each other due to innovations that are randomly distributed across the activities. But as soon a exchange becomes wise-spread, firms with an R&D strategy that focus on selected activities tend to perform better than other firms. This gives a certain stability of the specialisation structure, but the selective character of the firms capabilities implies that its detronisation from a strong market position means that it has to start more or less from scratch (since we have not considered a bankruptcy mechanism). The development of focussing strategy that to some extent insures against such problems is an important issue for further studies.

The R&D activities and their coordination with productive activities is not only an intrafirm problem. As pointed out by Richardson this is just one of the cases of closely complementary activities which may also suggest the application of different types of interfirm cooperation (see section 3). In the absence of markets for innovative results, the coordination problems related to innovations must either take place within individual firms, in close collaboration between a few firms, or in government-supported clearing houses or technology centres. In the present paper only the first of these possibilities has been covered (in sections 4.5, 5.5, and 5.6). These latter issues have to be left for later treatment but a few suggestions are e.g. found in Andersen and Lundvall (1997).

The treatment of Richardson's other concept, that of "similar activities", is more problematic. The reason is that this concept suggests that the structure of industrial production is to some extent a network rather than a tree. This means — as e.g. Richardson (1995) points out — that an activity at a higher level has connections to several lower-level activities.

Network structures are especially important for activities that are often considered as "key sectors" or as representing "generic technologies" (see e.g. Ames and Rosenberg 1965, Rosenberg 1982, ch. 3). The existence of such activities explains to some extent Richardson's (1972) notion of "similar activities", i.e. activities which require the same type of capability and which are often organised within an integrated firm. The emphasis on tree structures in the present paper excludes any simple application of this version of the concept of "similarity". The reason why trees are not simply exchanged by networks in the analytical schemes is that such a change implies a computational explosion and/or the application of arbitrary constraints. There are, however, several possibilities for the introduction of the concept of similar activities into the framework. For instance, we can in the vertical scheme introduce spill-over effects from the innovation of one activity to the productivity by which other activities are performed (or to the ease be which these other activities are innovated). What remains it to define which activities are subject to this effect. This set of activities might be all the activities at a certain level of the production tree or all left-oriented branches at a certain level or ...

Another important issue is to allow for the mobility of labour, money and information across firms. Actually, we do not have a full concept of firm before these topics are included. But these issues have to a larger extent been dealt with by the post-Schumpeterian "evolutionary economics" with which the analytical schemes of the paper are clearly affiliated. However, the paper has introduced several novelties for the simple reason that the analysis of "Schumpeterian competition" within this tradition has not hitherto dealt with the problems of disintegration and "economic complexity". On the contrary, this kind of modelling is often designed in a way which emphasise the distance to the analysis of the present paper. The first problem is that the post-Schumpeterian tradition has emphasised the concepts of "taciteness" and "idiosyncracy" to a degree that makes it is difficult to compare task structures across firms. However, in the present paper it has been assumed that these concepts are not necessarily related to the task structure and the activities of firms but rather to the character of the competencies used to perform the activities. In this way they help to explain the heterogeneity of competencies across firms and the "stickiness" of these competencies.

Another problem is that the "routine" concept, which underlies much of the Nelson and Winter tradition, has not yet been connected to the interdependent task structure of industry. However, we should note that the routine concept is to some extent synonymous with the competence concept, and the concept of "meta-routines" deals with the improvement of the competencies. Thus there is not a large distance to the assumptions of the disintegration approach. A more radical departure from the Nelson and Winter approach is implied in the present paper's assumption that firms upholds capabilities that they for a period do not practice. This is clearly against some of their basic assumptions, but much of the difference has been introduced for simplifying the vertical and horizontal analysis of the disintegration process. On the other hand, the Nelson and Winter tradition has no treatment of the problems related to the creation of outsourcing and market creation, so here is an area which is clearly open for further development. The present paper has tried to open up this part of the research agenda.

Notes

[1] My interpretation of the role of the foundational stories has been influenced by discussions with Nicolai J. Foss, Brian Loasby, and George B. Richardson.

[2] These formulations are taken nearly verbatim from the previous article of Richardson (1972).

[3] This is not the only possible use of the term “task”. If, for instance, the basic technology, management strategy (e.g. crafts organisation or Taylorism), and scale of production are more or less given, managers will operate as if they were able to define primitive subtasks. This viewpoint is driven to the extreme by Taylor (1911, 39) who also applies the concept of tasks. He states: “Perhaps the most prominent single element in modern scientific management is the task idea”. However, Taylor narrows down the concept by defining that “a task specifies not only what is to be done but how it is to be done and the exact time allowed for doing it.” Such a short-term definition makes the concept of tasks irrelevant in an evolutionary context. In the present paper a task simply defines “what is to be done”, e.g. an intermediate product with a certain function for the user. The questions of “how it is to be done” and “the exact time allowed for doing it” is fixed for a given firm in a given period. But the firm is always looking for better ways of doing its main task and for a new and more profitable main task.

[4] This subdivision had been studied by engineers and recorded in the French *Encyclopédie*.

[5] A major exception is the increasing demand for production-process-specified food products, like e.g. “organic” or “ecological” products (see e.g. Andersen and Philipsen 1998).

[6] The evolution and main elements of the post-Schumpeterian modelling tradition are sketched out by e.g. Nelson (1995), Silverberg and Verspagen (1997), Andersen (1997).

[7] To introduce a labour market for workers with heterogeneous competencies is far beyond the limits of the present paper. It is, however, a prerequisite for more realistic versions of the suggested models.

[8] In mathematics and computer science texts trees are normally depicted upside down, and the directions thus have to be reversed.

[9] The nodes of a binary tree are ordered in levels (distances from the root node), and the left descendant of a node is distinguished from the right one. Therefore, any activity and product can be described unambiguously: e.g. activity 8 in figure 1 is described from the root upwards as right, left, left, right (or RLLR). With a string of 10 characters, more than a thousand different nodes can be named. With a string of 20 characters, more than a million different nodes can be named. Binary trees are examples of a much larger class of ordered trees which is studied both by computer scientists and mathematicians (see the extensive account in Knuth 1997).

[10] The gap was originally suggested in Paul Samuelson’s iceberg model. It has e.g. been applied by Yang and Ng (1993).

[11] The same cannot be said about transaction costs related to opportunistic behaviour, so this type of costs goes beyond the analytical scheme presented in the paper.

[12] In the simple version of the analytical scheme we shall not allow firms with losses to exit. Both these firms and their employees stay in business and try to do better in the next round of production and exchange.

[13] The first, fourth and fifth step in the determination of innovative success are formulated in close relation to the Nelson and Winter (1982, chs. 12-14) model of “Schumpeterian competition”.

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