

# Escaping Satiation in an Evolutionary Model of Structural Economic Dynamics

By Esben Sloth Andersen

Dept. of Business Studies, Aalborg University  
Email: esa@business.auc.dk

Paper to be presented at the workshop on  
“Escaping Satiation: Increasing Product Variety,  
Preference Change and the Demand Side of Economic Growth”,  
Max Planck Institute for Research into Economic Systems,  
Jena, 11-13 December 1997.

**ABSTRACT:** This paper presents the problem of satiation in relation to a model of evolutionary endogenous growth. The model represents an attempt to provide an evolutionary economic micro foundation to Pasinetti’s scheme of the structural economic dynamics of a labour economy. Like this scheme the model deals with an economic system with a varying number of sectors, each of which is producing a consumption good. Consumers have a hierarchy of goods, and they first consume a higher-order good when they are fully provided with the lower-order goods. The goods are produced within consumer-producer firms which organise both production and consumption for their workers. Production takes place by means of labour and knowledge. Through innovative activities firms increase their productivity with respect to individual goods. The long-run consequence of this is that labour becomes available for the production of new consumption goods. If such goods are not provided to a sufficient degree, “technological unemployment” will emerge. If there is slow productivity development in the production of new goods, the overall rate of growth will slow down irrespectively of productivity growth in old sectors. Thus, to enhance long-term growth there is a need of “anticipatory R&D”, i.e. R&D which produces designs for novel goods in the consumption hierarchy and increases productivity in the production of these goods. However, this is not necessarily done even in economies where we find wide-spread activities on product innovation and process innovation.

**KEYWORDS:** Evolutionary modelling, endogenous growth and development, structural economic dynamics, satiation of demand, Robinson Crusoe.

**ACKNOWLEDGMENTS:** The research underlying the paper has been supported by the Danish Research Unit for Industrial Dynamics (DRUID). The paper has been written in relation to the project on “Dynamic Reconstruction of Unfolding Industrial Diversity by Interactive Computing” (DRUIDIC). The contours of this project can be seen from Andersen 1996a-c; 1997; Andersen et al. 1996; Andersen and Lundvall, 1997.

## 1. From Pasinetti's scheme to an evolutionary model

This paper presents a model of evolutionary growth and development in which satiation of demand plays an important role in determining structural economic dynamics. The model has many purposes and backgrounds (including new growth theory), but it can most easily be understood as an attempt to provide an evolutionary economic micro foundation to Pasinetti's (1981; 1993) scheme of the structural economic dynamics of a pure labour economy. This relationship builds on common purposes of both Pasinetti's and the present model. The primary goal of both models is to bring out clearly one of the best documented empirical regularities of economic growth: that long-term growth is always related to major changes in the composition of the economic system. The two models also take serious another, somewhat more disputed, stylised fact, namely that increased diversity and variety of the economic system is an integral part of long-term economic growth. Finally, the models tries to demonstrate that satiation of demand is a major factor determining economic growth and structural development—especially in terms of diversity and variety.

For the present purposes we shall consider the following short-term aspects of the Pasinetti scheme: In any period  $t$  the economic system consists of  $n_t$  sectors, each of which is producing a homogeneous consumption good. The size of output of any of the  $n_t$  goods of the economy is determined by means of its per capita consumption coefficient, i.e.  $Q_{it} = c_{it}N_t$ , where  $c_{it}$  is the consumption coefficient of good  $i$  and  $N_t$  is the size of the population of workers. The production of  $Q_{it}$  takes place by means of labour and knowledge. The sectoral production function is characterised by constant returns to scale, so that employment is determined as  $L_{it} = Q_{it}/a_{it}$ , where  $L_{it}$  is the number of workers employed in sector  $i$  and  $a_{it}$  is the labour coefficient (each worker is supplying a fixed amount of labour per period). Finally, we find employment per capita,

$$\frac{L_t}{N_t} = \sum_{i=1}^{n_t} \frac{c_{it}}{a_{it}}.$$

Normally Pasinetti assumes that the system fulfills the full-employment condition  $L_t/N_t = 1$ .

This presentation makes clear that the movement over time of output and employment in the Pasinetti system is simply determined by the movement of two variable-length vectors of exogenously determined parameters, the labour coefficients  $\mathbf{a}_t$  and the consumption coefficients  $\mathbf{c}_t$ . Pasinetti gives a stylised story about the movement of these

parameters. The labour coefficients are assumed to increase over time, so that  $a_{i,t+1} > a_{it}$  for all  $i$ . This technical progress is assumed to be sufficient to allow per capita income to increase over time. On the other hand, each individual consumption coefficient undergoes a more complex movement which depends on the hierarchy of consumption goods. Except for the most basic goods, any good  $i$  has the following story: In the beginning the good is not consumed at all, but when per capita income reaches a certain level the good starts to get consumed; then the consumption coefficient increases until a maximum level is reached, and this level is then kept fixed (unless we are facing an inferior good).

It is the asymmetric movement of the labour coefficients and the consumption coefficients that creates the drama within the Pasinetti scheme. The potential problem is one of satiation of demand, and it arises when new goods are introduced too slowly into production and/or consumption. If this is the case, labour productivity and incomes continue to grow while consumption becomes more and more satiated. This means that  $L_t/N_t < 1$ , i.e. we observe what might be called “technological unemployment”. One strategy against this unemployment is to reduce labour time; another strategy is to try to introduce new consumption goods (i.e.  $n_{t+1} > n_t$ ). In both cases there is a need of consumer learning: how to exploit extra leisure time and/or how to utilise new goods.

The short description of long-term dynamics within the Pasinetti scheme demonstrates that it captures, maybe in the simplest possible way, the stylised facts of the structural transformation and increased complexity of the economic system. This result is, however, obtained by exogenous changes in labour coefficients and consumption coefficients. This treatment of the core issue (learning) as a *deus ex machina* is only satisfactory as a first approximation. But the scheme has shown no changes in this respect since its original presentation more than thirty years ago (Pasinetti 1965). Similarly, the scheme has upheld its pre-institutional (“natural”) character. It is thus high time to provide a micro foundation for Pasinetti’s purely formal scheme.

With respect to the evolution of labour coefficients, the Nelson and Winter (1982) tradition of evolutionary economic modelling supplies a potential micro foundation. From this tradition we know that economic evolution can be depicted as a process in which firms follow rules or procedures that are occasionally mutated or adapted. We also know that an important example of economic evolution takes place within an industry (or a one-sector economy) where new process techniques are introduced and imitated. These and other aspects of the Nelson and Winter model have to some extent defined a “paradigm” for further research, even in the form of an evolutionary growth theory (see Silverberg and Verspagen 1995; Nelson 1995, 67-72; criticism in Romer 1993). But this evolutionary economic tradition has been weak in supplying foundations for a treatment of the evolution of consumption coefficients. The present paper tries to demonstrate a

simple way in which this situation can be changed, namely by operating with hierarchical consumer preferences and with economic agents that are both producers and consumers.

The evolutionary model of structural economic dynamics will be presented in three steps. First, Pasinetti's idea of an institution-free or "natural" level of analysis (in the tradition of classical economics) will be driven to its extreme by analysing the structural economic dynamics of a Robinson Crusoe economy (section 2). Then a simple version of a multi-agent model of evolutionary endogenous growth is presented (section 3). In this "Robinsoniana" model a large number of consumer-producer firms ("Robinsons") are involved in specialisation and trade. Simulation experiments are made for this model with special emphasis on the consequences of different types of specialisation of R&D activities (section 4). Finally (section 5), the paper discusses more explicitly the problem of escaping satiation in the "Robinsoniana" model.

## 2. Satiation in a single Robinson Crusoe economy

A first approximation to a micro foundation of the Pasinetti scheme can be sketched in terms of a Robinson Crusoe economy where production takes place by means of labour and knowledge alone. To model the structural dynamics of this economy, we have to recognise that "Robinson Crusoe Was Not Mainly a Resource Allocator" (Simon 1989, 471). Contrary to the normal use of him in economics (White 1987), any thorough reading of Defoe's (1938) novel demonstrates that Robinson was not mainly engaged in dealing with known and existing resources. It was rather his efforts in "creating new ways of dealing with his environment [that] kept him alive and eventually comfortable. Such creating is a proper model for the economic history and future of humankind; allocation is only its handmaiden." (Simon 1989, 471) Thus we start with Robinson Crusoe as a boundedly rational man with a high degree of creativity. It is such a Robinson that builds a complex production and consumption system, and to do so he needs to emphasise innovative activities.

In any period of time Robinson uses his knowledge of productive algorithms and product designs in the production of a set of goods that under the given conditions maximise his utility. In principle, Robinson can produce an infinite number of types of goods, and the specification of all these goods are known to the model builder. Robinson is, however, much more myopic. The reason is that Robinson has a utility function that orders the consumption goods hierarchically (like in Pasinetti 1993; Verspagen 1993, Ch. 7). This hierarchy is reflected in the index numbers for consumption goods,  $1, 2, \dots, i, \dots$ : a good is more basic than another if it has a lower index.

The model has a very simple interpretation of the (Austrian) notion of a hierarchy of consumption goods. For each good there is a physical maximum per capita  $Q_i^{\max}$  which,

for simplicity, is equal for all goods. If maximum utility has been obtained from goods  $1, \dots, i$ , then the utility increases in proportion to the consumed quantity of good  $i+1$  up to its physical maximum. Expansion beyond that maximum does not influence utility. Expansion of the quantity of good  $i+2$  before good  $i+1$  has reached its maximum increases utility much less than a similar amount of good  $i+1$  would have done. Thus Robinson's historically given standard of living,  $G_t$ , can normally be characterised by the number of goods that are consumed up to their maximum and the degree to which the last good has been consumed. If  $G_t = 2$ , it means that the first two goods have been consumed fully. If  $G_t = 2.5$ , then two goods have been consumed fully and the third good has been consumed in a quantity which is half of its maximum. These specifications of the utility function are loosely compatible with a generalised version of Engel's law.

The growth of Robinson's standard of living cannot be determined independently of the research and production conditions in the Robinsonian economy. Research gives probabilistic results and production gives deterministic results. To simplify the analysis we shall assume that Robinson has a desired number of working hours ( $L$ ) and that he has a fixed split of these working hours between research and production (given research productivity and his intertemporal preferences).

In such a set-up we consider a situation where Robinson is able to produce more than the first three goods, i.e. that he has left some working hours when he has produced the first three goods up to their maximum. Thus

$$L^{\text{prod}} > \frac{Q^{\text{max}}}{a_{1t}} + \frac{Q^{\text{max}}}{a_{2t}} + \frac{Q^{\text{max}}}{a_{3t}},$$

where  $L^{\text{prod}}$  is the desired number of labour hours in production,  $Q^{\text{max}}$  is the maximum consumption of any good, and  $a_{it}$  is the labour productivity for good  $i$ . This equation does not necessarily mean that  $G_t > 3$ . The reason is that although Robinson in principle knows the type of good that fulfills his fourth need, he has to discover a product design before he can produce a product within that type of good. As long as he is not able to find such a product design, he will encounter a situation with satiation of consumption and enforced reduction of his working hours or enforced increase in his research activities. He might even find product designs related to higher-ordered goods before he finds the design for good 4, but this does not change the situation much because the consumption of e.g. good 5 before any consumption of good 4 gives only little addition to overall utility. Thus there might be satiation of demand although higher-ordered goods are known and consumed sporadically.

As soon as Robinson has found a design for good 4, the situation is radically changed. The reason is that we shall assume that Robinson is able to produce copies of any product design that is known to him, although this production will initially take place with very low productivity. Given his utility function, Robinson will immediately start to use his unused amount of desired production labour hours for the production of good 4. His research activities also starts to consider how to increase the initially very low productivity with respect to the production of good 4 (and other goods that he is able to produce). As a result Robinson will increase his production of good 4 in a stepwise manner, and at some point of time he will start to consider good 5. However, if Robinson has not had any anticipatory improvements of the productivity of good 4 production, it may—for stochastic reasons—take a long time before he is able to consume this good up to its maximum.

It is now obvious that the way Robinson spends his research time is important for the long-term growth of his standard of living. Growth will be enhanced if he does not wait to look for a new product design until all the lower-level goods has been fully consumed. Similarly, it may be an advantage to start to improve the productivities of known goods before they have entered actual production and consumption. However, such a behaviour is not found in the boundedly rational Robinson Crusoe of Defoe's novel. Here it is acute problems that lead to research activities. In the present model it could be satiation of demand and the emergence of a residual of labour (Pasinetti's "technological unemployment") that determines the introduction of a new focusing strategy in Robinson's research work. Thus we arrive at an oscillating solution to Robinson's main problem of dividing his innovative activities between on the one hand increasing the productivity in production of existing goods and on the other hand creating new goods and related methods of production. By solving this problem over and over again, our fictitious Robinson is able to replicate much of Pasinetti's story of the structural evolution of economic life.

### **3. The Robinsoniana model**

#### **3.1. Motivation and overview**

To develop further the story of structural economic dynamics we need to turn from the individual Robinsonian economy to an economy with many interacting agents. To stick to the original story we study a large number of potentially interacting Robinsons, each occupying a small island in the archipelago of Robinsoniana. Each Robinson has his own "household-firm" that organise the production and consumption of his fixed labour force; each Robinson can engage in bilateral exchange of goods; but although goods can be transported between the islands, Robinsons do not migrate and do not work for other

Robinsons (they are not transformed into “Fridays”). In this way we create an economic system which is placed halfway between Pasinetti’s scheme of a “natural” or institution-free economic system and full-blown capitalist systems with money, labour markets and financial markets.

To establish a rapid intuition about the consumer-producer firms (cf. Yang and Ng 1993) of Robinsoniana, the reader may think of firms in an economic system where very-long-term labour contracts have come to dominate, but there are several alternative interpretations. One possibility is that our “firms” are consumer-producer cooperatives, another that we are facing consumer-producer households of the peasant and artisan type. 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 model’s insights of how an economic system may be created from scratch through an innovation-driven process.

Basically, the Robinsoniana model functions like in the above description of the evolution of Robinson Crusoe’s economy except that we now take into account the possibility of specialisation and exchange. The outcome of a successful process innovation is the introduction of a new algorithm about the process of production with respect to a particular good. Due to the random character of innovative results, productivity differentials between the Robinsons will necessarily emerge—thus creating the dynamic comparative advantages that are the background for their specialisation and bilateral exchange. As income increases, consumption is expanded to encompass an ever-increasing range of goods. Thus a more diversified economic system emerges. The problem is, however, how fast this process is. This depends on how the Robinsons cope with satiation of demand—both “satiation in the narrow sense” where there is a lack of product designs for the “next” goods in the hierarchy and “satiation in the broad sense” where the “next” goods are produced with so low productivity that they function as a brake on further growth.

The Robinsoniana model that depicts the initial stages of an economy that undergoes both growth and development (i.e. structural transformation and diversification). The economy has only one type of agent, Robinsonian firms that function both as producers and consumers. The “employees” of a firm are also its owners (with equal shares). 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 Robinsonian firm is to maximise the utility of its employee-owners.

### 3.2. 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  $1, 2, \dots, i, \dots$ , 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,  $G_{jt}$ , is simply the number of goods consumed up to their maximum. If e.g.  $G_{jt} = 5.64$ , it means that the employee-owners of firm  $j$  in period  $t$  have maximum consumption of the first 5 goods while they consume 64% 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 than hierarchically consumed goods.

### 3.3. Production

The economy is 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. All Robinsonian firm have the same number of employees (e.g. 1).

Labour can be used to produce any of the goods in the consumption hierarchy as well as for R&D. Each firm has a specific labour productivity for each good, and the productivities are independent of the size of production. If firm  $j$  spends one unit of labour on good  $i$ , it produces  $a_{ijt}$  units of this good. If it spends  $L_{ijt}$  units of labour, it produces  $Q_{ijt} = a_{ijt}L_{ijt}$ . The firm’s open-ended list of productivities  $(a_{1jt}, \dots, a_{ijt}, \dots)$  reflects its private set of production algorithms. The algorithms can be improved by R&D. Algorithms that have not been improved beyond the basic level of knowledge have high unit labour costs.

### 3.4. 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 enter 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.

### 3.5. R&D investment

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. This R&D falls in two parts that are motivated by two outcomes: process innovation and product innovation. We shall focus on process innovation but not omit product innovation.

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 four steps. 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 effort. Second, we see which of the productivities 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 find a new productivity. 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 firms or with an exogenous, science-based mean. Fourth, the firm implements the new productivity in the next period if it is better than the previous productivity (i.e. if  $a_{ij,t+1} > a_{ijt}$ ).

Each firm has a strategy of how to focus the attention of R&D work to the different goods of the hierarchy of consumption. This focusing strategy is modelled as a conditional decision. Since the hierarchy is infinite, it is obviously non-sensical to focus with equal weight on all possible goods. 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 the production of a particular good. When exchange is introduced, this strategy can also be applied. But with highly developed exchange, firms come to focus on improving production of a single good. 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 when other firms take over the market, the specialised firm will confront a major set-back in its standard of living. There are many ways of insurance against such a catastrophe. The simplest, but not the best, of these strategies is to spread equally across all the goods that are consumed by the firm.

To produce a particular good the firm needs to find an appropriate product design. The method for finding such designs is nearly equal to the method of process innovation—except that we shall (in the main part of the paper) assume that all product designs for a particular good are equivalent. The issue of an adequate focusing strategy is even more important in the case of product innovation than in the case of process innovation: the inability to find a product design for the next good in the hierarchy of goods can effectively block growth in the Robinsoniana model.

#### **4. Simulation of the structural dynamics in Robinsoniana**

In relation to the Robinsoniana model a set of simulations have been performed. Basically they explore how growth in individual and average standard of living ( $G_{jt}$  and  $G_t$ ) is influenced by the introduction of exchange as well as by different technological regimes and focusing strategies. Emphasis is put on the focusing of R&D since this theme is most directly related to the problem of satiation. However, only process innovation is taken into account. This means that we—for the sake of simplicity—assume that all Robinsons have brought with them from the Old World a knowledge of the product designs of all the goods that are produced during the simulation runs.

##### **4.1. Basic parameters and computational structures**

The simulations (cf. the programming tools used in Andersen et al. 1996) operate with 6 firms which each have one employee (who delivers 1.05 units of labour). All firms allocate their labour endowment so that 1 unit of labour is used for productive activities and 0.05 units of labour are used for R&D. The productive labour is allocated in order to maximise the standard of living, given that the maximum consumption of each good is

0.5. All firms have knowledge of the product designs needed for the production of the first 10 goods. The level of generic knowledge is so that all goods can be produced with a productivity of 0.5. This means that by applying generic technology each firm can produce 1 good up to its maximum or, in other words, the generally available standard of living is 1.

To get a quick startup of the simulation it is assumed that all firms have initially obtained some private knowledge. For each firm and each good the (logarithm of the) productivities of the first 5 goods are obtained from a normal distribution with a mean equal to the (logarithm of the) level of generic knowledge. Thus firms are able to improve the generic knowledge in half of the cases. The variance is so large that the average autarkic standard of living is raised to about 2. However, if all firms obtains access to the best-practice technology, the level of the standard of living starts from about 5 (see figure 1.a).

Whether the existence of substantial productivity differentials between firms leads to exchange depends on the share of transaction costs. In some experiments it is set to 1 so that the buyer receives none of the supplied goods. In other experiments the share of transaction costs is 0. In both cases the computational process starts by depicting the negotiation process according to the algorithm of section 3.4. Then it is calculated how much firms produce and exchange, and finally their standard of living is calculated.

In parallel with production and exchange firms perform their innovative activities. Innovative results occur according to a Poisson process in which it on average takes 4 periods for a firm to make one innovation. This innovation is related to one of the goods. Innovations are distributed uniformly between the goods that are dealt with in R&D work. Firms' R&D can either deal with all goods within their horizon of interest or they can focus few goods that they produce for sales and/or that represent their best productivities in comparison with other firms. Finally the new (logarithm of the) productivity for the selected good is obtained from a normal distribution with the (logarithm of the) existing productivity as the mean. Thus there is cumulativeness in each firm's productivity development with respect to each good.

#### 4.2. Technological development under autarky

To obtain a quick understanding of the main features of the model it is convenient to start from a set of autarkic Robinsonian firms (like the one described in section 2). We shall obtain this situation by setting the transaction costs' share to 1. This means that even a strong technological development and the related productivity differentials cannot overcome transaction costs. Instead all Robinsonian firms develop independently of each other. Under this condition it is easy to follow the consequences of technological

development. This is demonstrated in figure 1 which records the evolution of 5 autarkic firms during a simulation over 100 periods.

Although all firms have the same technological conditions and the same behavioural rules (including the strategy of “polyhistorians”, i.e. to improve knowledge on all fronts), they develop differently because of differences in their initial conditions and in their probabilistic success in R&D work. Of special importance is the assumption of cumulative technological development which means that a firm may become gradually better in each area. This means that productivities will (normally) be improved in a step-wise manner.

A typical pattern of productivity improvements of an individual firm with respect to 5 goods is recorded in figure 1.a. Here we see the evolution of the reciprocal productivities ( $1/a_{ijt}$ ) for firm 6. This firm has by assumption a reciprocal productivity of 2 for all unexplored goods hierarchy, but it can only produce the goods for which it has found a product design (this is by assumption the first 10 goods). In the initial situation the firm has tried to improve the productivity of the first 5 goods, but no improvement has initially been obtained for good 4. The firm has no luck in improving this productivity during the 100 periods of the simulation. However, for all other goods we see a step-wise improvement of the productivities. For instance, the reciprocal productivity of good 5 starts from about 1 1/3 and ends with less than 2/3. In the latter case one unit of labour will produce more than 1.5 units of output of good 5. On the other hand there is no improvements with respect to good 4. Here a unit of labour provides in all 100 periods 0.5 units of output.

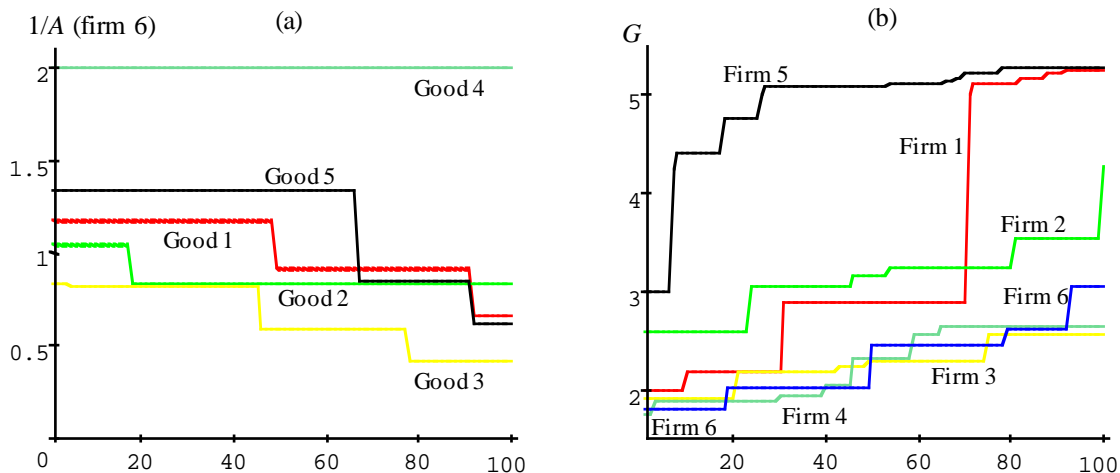


Figure 1. (a) Firm 6’s reciprocal productivities ( $1/a_{ijt}$ ) for 5 goods. (b) Average standard of living ( $G_{jt}$ ) for 6 firms under autarky (including firm 6).

As a result of its productivity development firm 6 undergoes a slow growth of  $G$ , the level of the standard of living of its employee-owner. In figure 1.b we can see that firm 6

in the beginning is able to obtain a standard of living of nearly 2, i.e. that it provides the maximum consumption of good 1 (0.5 units) and nearly the maximum consumption of good 2 (nearly 0.5 units). At the end of the simulation the living standard is a little more than 3, i.e. the first 3 goods are supplied fully while a little of good 4 is also produced.

Figure 1.b also shows information about 5 other firms. Initially most firms have a better living standard than firm 6. This is due to the initial distribution of productivities. The trajectories over the 100 periods is due to the cumulative technological development of individual firms. The movement of  $G$  also shows a step-wise pattern which gives the lucky ones an advantage. But the case of firm 1 demonstrates that a random sequence of innovations in the “right” goods are able to bring this firm from the bottom to the top of the distribution of standards of living—where firm 5 has been during the whole simulation.

Figure 1.b also demonstrates that firms 1 and 5 have reached a ceiling where the growth rate decreases. The reason is that they have not changed their focusing strategy. This means that they have not started to improve the reciprocal productivity of 2 with respect to good 6. This is obviously irrational, especially for firm 5, but it demonstrates how a lack of attention to the productivity of the production of the front-end goods can function as nearly as strong a brake on growth than the lack of finding the “next” product design (a possibility which under the current assumptions will be reached when good 11 comes into consideration).

The R&D strategy applied in the simulation is not the best for autarkic firms (instead it is used to simplify the introduction of exchange). Thus the performance of each autarkic firm can be improved by changing the focusing strategy of R&D work. For instance, firm 6 in figure 1.a continues to put equal attention of R&D work to all 5 goods over all periods. This is not realistic for at least two reasons. First of all, good 5 is not produced at all during the 100 periods. So why bother about this product. Second, the firm does spend an equal amount of labour on all goods. It would be an obvious strategy to allocate R&D work in the same proportion as productive work. To take an example, the firm could emphasise innovations with respect to good 1 after it has made an innovation with respect to good 2 around period 20. Actually we see an innovation with respect to good 1 around period 40, but this improvement is due to a purely random event within the generalist strategy—not to an increased attention to good 1 innovations.

### 4.3. Autarky vs. exchange

The conditions which allows the emergence of exchange in Robinsoniana can emerge in different ways. In the simulations we have increased productivity differentials by letting the firms follow a generalist R&D strategy. As soon as some trade is present we can

promote further trade by adding an endogenous decrease in transaction costs. In the present prototype model we simply assume an exogenous drop in transaction costs, however. In the simulation runs recorded in figure 2.b we make the assumption is that all barriers to trade have been overcome (the transaction costs' share is 0). Given this assumption as well as simple productivity differentials, we see the emergence of exchange between firms.

The introduction of specialisation and trade in Robinsoniana dramatically changes the conditions of firms as well as their R&D strategies. This change is due to the fact that firms now have the possibility of exploiting the model's increasing returns to the application of innovations. Their situation is simply that the costs of making an innovation is given while the benefits differ with the volume over which the innovation is used. If the firm makes an innovation with respect to a good that it does not produce, there are no benefits from the innovation. If the firm produces for its in-house consumption, then benefits are limited by maximum consumption. The fullest use of the benefits emerge from becoming a specialised seller of the innovated good. The system-level consequence is that the average level of consumption is higher and its growth is larger than in the case of autarky.

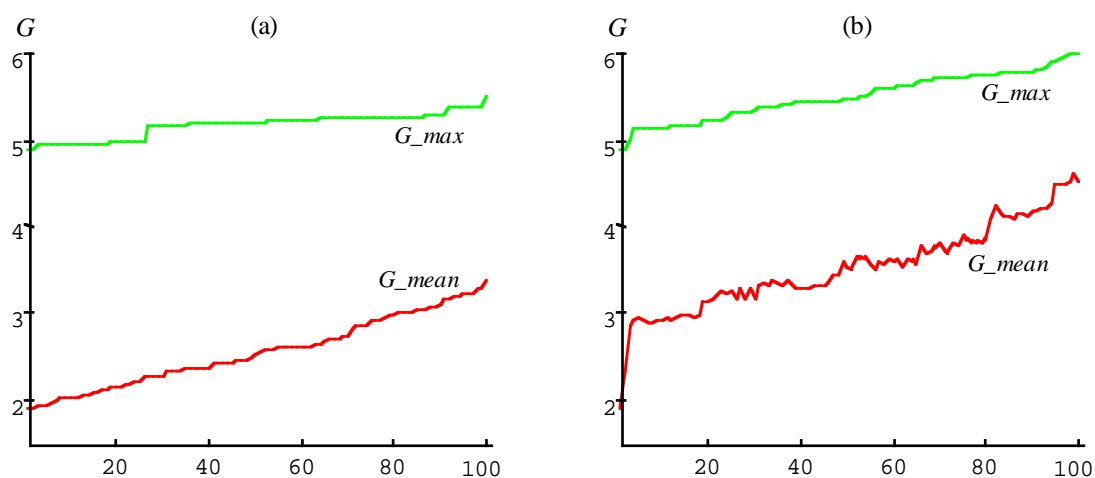


Figure 2. Average actual and potential standard of living ( $G^{\text{mean}}$  and  $G^{\text{max}}$ ) in systems (a) without exchange between firms and (b) with exchange between firms (averages of 5 runs).

Figure 2 compares the average standards of living ( $G^{\text{mean}}$ —also called  $G_t$ ) for situations with autarky and bilateral exchanges between firms. Using the standard assumptions (see section 4.1) we see much variance between outcomes that a based on different sequences of random numbers. Therefore, we record average results from 5 simulation runs. Even with this degree of averaging we still have left a visible variance—especially in the runs with exchange (figure 2.b). The reason for this result is obvious if we consider figure 5.

The difference between autarky and exchange can be seen by comparing the average actual standard of living in figure 2.a and 2.b. Here we start from a situation with large productivity differentials. Therefore, a significant increase in the standard of living—from less than 2 to about 3—can be obtained by introducing exchange. This exchange is, however, far from “perfect”. The reason is that some firms have a larger degree of market power than others. Therefore they can impose advantageous exchange rates with respect to weaker firms, and this diminishes the level of exchange and the overall standard of living compared with an—unrealistic—situation with equal market power for all firms.

Both under a regime with autarky and with exchange we see a gradual increase in the average standard of living in Robinsoniana. The starting point is exactly the same, but gradually differences emerge between the two regimes. The reasons for these differences can be seen from the development of the maximum potential standard of living ( $G^{\max}$ ) under the two regimes. This measure is simply the obtainable standard of living given that all production take place with best-practice technology. A comparison between figures 2.a and 2.b shows a clear difference in this measure. The reason is that the best-off firms start to focus the attention of their R&D work on higher-level goods and occasionally they moves the front forward. In relation to figure 2 the frontier goods are the goods beyond good 5. Since these goods come more to the attention to goods with the higher, exchange-based standard of living, the frontier moves faster in figure 2.b.

#### 4.4. Innovative competition with generalist and specialised R&D

The results of figure 2 reflects the assumption that in Robinsoniana there are even technological opportunities with respect to all goods and that all firms follow a generalist R&D strategy, i.e. that they spread their R&D attention evenly across all goods from the bottom of the hierarchy up to the front of their horizon of interest. But although this strategy is helpful in introducing into an autarkic system a significant degree of productivity variance, it is not an obvious strategy to follow for firms that consider a relatively stable exchange system as a permanent phenomenon. For such firms it is obvious to consider some degree of specialisation of their R&D work. A simple example of such a specialisation strategy is compared with the generalist (or polyhistoric) strategy in figure 3.

In a Robinsoniana where all firms follow the generalist strategy all firms want to improve their productivity relating to all goods. To dramatise the results a little *vis-à-vis* the results recorded in figures 1-2 we now start from a horizon of interest consisting of 4 goods. The horizon of interest is expanded when consumption reaches a higher-level good, starting from good 5.

In figure 3.a the results of 6 firms' attention to a single good (good 2) is recorded. All except one (firm 1) has been able to improve their productivity with respect to this good. But in the exchange regime only one of two of the best firms will at any point of time use their knowledge with respect to good 2. This is the background for the R&D strategy followed by all the firms in the simulation recorded in figure 3.b. Here only firm 3 and firm 2 have obtained an improvement in their productivity with respect to good 2.

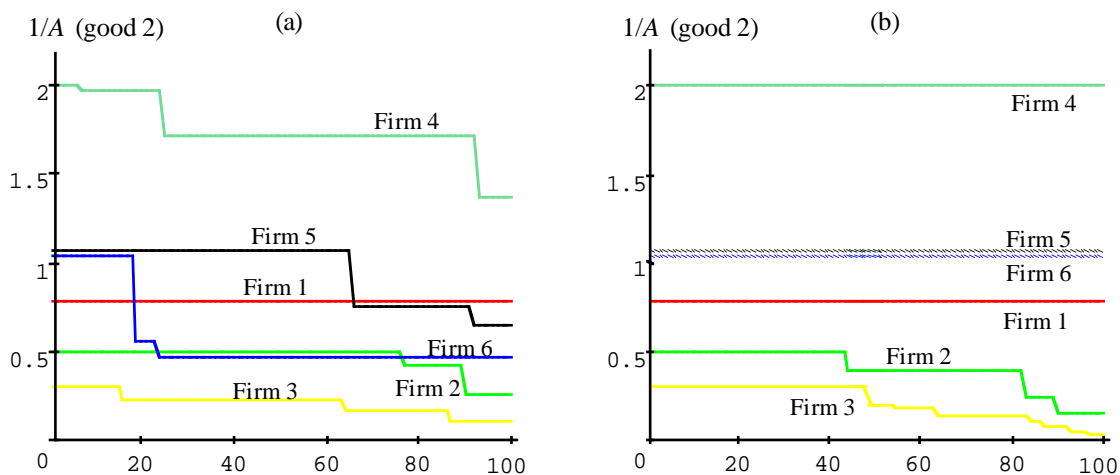


Figure 3. Evolution of reciprocal productivities ( $1/a_{ijt}$ ) for 5 firms with respect to good 2 in (a) a system of "polyhistorists" and (b) a system where each firm focus on a few of its strongholds.

These results reflect that each firm at any point of time focuses its attention on its two best goods (and the system-level frontier good if its consumption has reached this level). The result of this specialisation is a marked improvement in the level of productivities of firms that are relevant for the system-level performance (if we had recorded  $a_{ijt}$  instead of  $1/a_{ijt}$ , this would have been clearer). Since we have changed one assumption (the initial set of goods within each firm's horizon), the evolution is now different from figures 1-2. Therefore we give aggregate results of the run. These results (that are nearly comparable with figure 2) are recorded in figure 4.

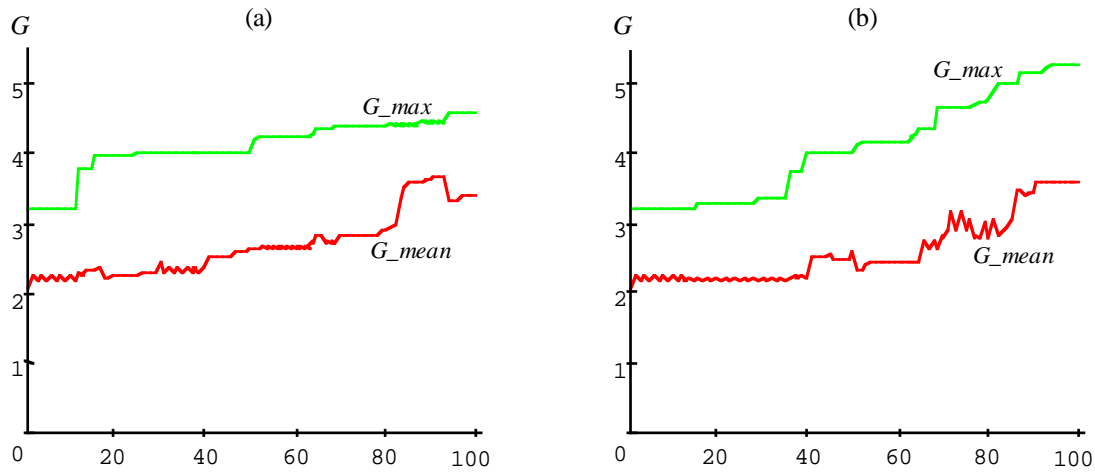


Figure 4.  $G$  at the technology front and in actual practice in (a) a system of “polyhistorians” and (b) a system where each firm focus on a few of its strongholds.

By comparing figures 4.a and 4.b we see that the difference between the polyhistoric and the specialist R&D strategies are more marked with respect to the technology-front standard of living than the actual standard of living. The reason is mainly that the specialist strategy introduced a higher degree of monopoly power than the polyhistoric strategy where all firms compete all the time by means of knowledge creation. This cannot directly be seen from the figures. But another difference is easy to illustrate at the level of the standard of living.

By comparing figures 5.a and 5.b we can appreciate that the specialist R&D strategy introduces more marked coordination problems than the generalist strategy. This is especially obvious in periods 60 to 90 where much instability emerges in figure 5.b. One of the reasons can be seen by considering firm 5. This firm is not able to obtain a single bilateral exchange, so it has to stay at its autarkic standard of living. However, in figure 5.b it obtains occasional exchanges from period 70. This happens in a period where there is a general instability in the pattern of specialisation—after a semi-stable period between periods 40 and 70. But the Robinsoniana system reaches a new stable pattern of specialisation before period 90.

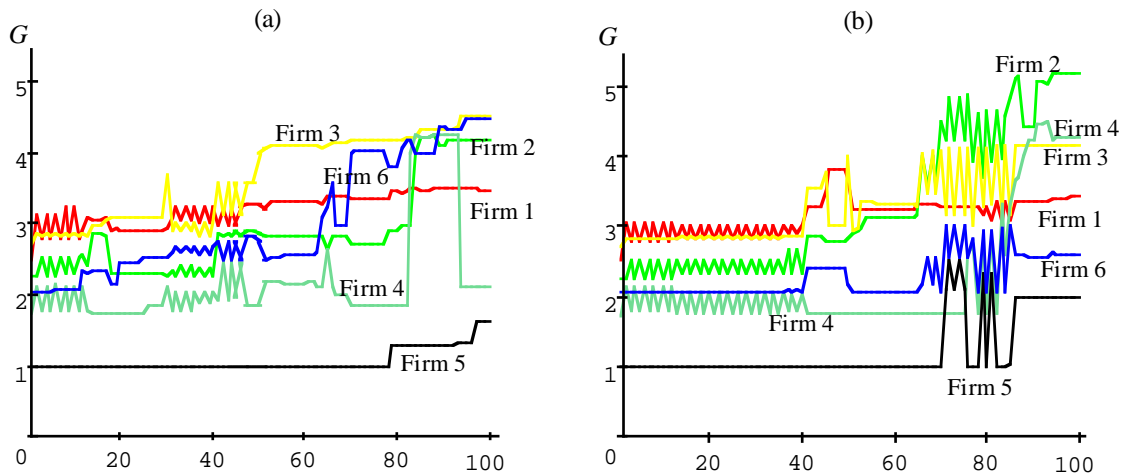


Figure 5. Average standard of living of firms in (a) a system of “polyhistor” and (b) a system where each firm focus on a few of its strongholds.

In instable situations there is stronger competition and many firms cannot uphold their position. Since they cannot go bankrupt, they will however have new chances. Ultimately, the assumed cumulative technological regime can ease the problem. But firms can try minimise the time it takes to stabilise their situation by following more advanced R&D strategies where they concentrate in a more complex manner on actual and potential strongholds with respect to trade and productivity. However, simulations demonstrate that there will normally be shifts between stasis and instability. The microlevel “solutions” will not normally stabilise the Robinsoniana system. The future introduction of labour and capital markets into the prototype model will point to new sources of instability.

## 5. Problems of satiation in Robinsoniana

### 5.1. Summarising the results

The Robinsoniana model has tried to provide important elements of a micro foundation of the Pasinetti scheme of economic growth and development. Even in the Robinsoniana case the long-run consequence productivity growth in a multi-sectoral economy is that labour becomes available for the production of new consumption goods. If such goods are not available to a sufficient degree, the macroeconomic consequence is that “technological unemployment” will emerge. A related problem, namely that productivity growth is slow for front-end goods, does not lead to “unemployment” but just to a slow-down in aggregate growth. In the former case we may talk of problems of “satiation in the narrow sense” where there is a lack of product designs for the “next” goods in the hierarchy. The latter case may be related to “satiation in the very broad sense” where the

“next” goods are produced with so low productivity that they function as a brake on further growth.

The simulation omitted “satiation in the narrow sense” by the assumption that product designs for the first 10 goods were available. This assumption allowed us to explore the dynamics created by differential productivity growth across firms and sectors, including problems of “satiation in the broad sense”. Even in the case where product designs for new goods were no constraint, we saw that there might occur a slow productivity development in the production of new goods which slowed down the overall rate of growth irrespectively of productivity growth in old sectors. Thus, to enhance long-term growth there is a need of “anticipatory R&D”, i.e. R&D which produces both designs for novel goods in the consumption hierarchy and increases productivity in the production of these goods.

The solution to the problem of “anticipatory R&D” is not necessarily found, even in economies where we find wide-spread activities on product innovation and process innovation. With respect to the Robinsoniana economy we observe a trade-off between on the one hand the need to stabilise the economy in a way that allows the specialisation of R&D and on the other hand the attempts to solve the problems of satiation of demand. The problem is that specialised firms are likely to have much larger problems in exploring the frontier of the consumption hierarchy than the generalist firms of a turbulent economy.

## 5.2. Satiation in an extended model with a double consumption hierarchy

The Robinsoniana model has implemented the basic Pasinetti scheme rather than extending it. This might be problematic when we try to relate to present-day problems where we encounter a surprising variety of product designs. Can there really be a problem of satiation of demand in such an economic world? This question is so central that we cannot simply dismiss it as being beyond the limits of the present paper. Instead we shall see how the Robinsoniana model can be extended to cope with the question by introducing a double hierarchy of goods.

The first hierarchy has already been presented. We may say that it concerns the diversity or breadth of the set of consumed goods as reflected in the standard of living measure (perceived  $G_{jt}$ ). Based on this simple sequential hierarchy we can, however, construct an embedded hierarchy. This second hierarchy concerns the variety of subgoods (variants) by which each of the species of goods of the first hierarchy is implemented. The relevant measure in this connection is the perceived average of variants per species of good or the perceived average height of the “trees of variants” (implemented as binary trees; cf. the “production trees” in Andersen 1996c). This measure may be called perceived  $H_{jt}$ .

In relation to the second (nested) hierarchy we only consider an individual good  $i$  as a first approximation to the fulfillment of a complex need. Instead of satisfying the need with e.g. two units of good  $i$ , the consumer prefers to have one unit of each of two variants of the good that covers different aspects of the need. Thus good  $i$  at level 0 becomes bifurcated into good  $i_1$  and good  $i_2$  at level 1. Similarly, good  $i_1$  may become bifurcated into good  $i_{11}$  and good  $i_{12}$  at level 2. A continued process of bifurcation means a maximum of 2 variants at level 1, 4 variants at level 2, and  $2^n$  variants at level  $n$ .

The important question is whether and how the maximum consumption of the goods of the  $i$ th family of goods is influenced by its increased variety. The answer depends in the previously defined standard of living (measured in terms of  $G_{jt}$ ) relative to  $i$ . If the standard of living is not significantly larger than  $i$ , then although the consumer slightly prefers variety of consumption, there is no increase in consumption (and no willingness to pay more). As the distance between the index of the good and the standard of living increases, the preferred level of variety increases. To be more specific, the maximum consumption of each of the variants at preferred level  $n$  may be set to  $n/2^n$ . Thus, if the preferred level of variety within the  $i$ th family of goods is 0, then 1 unit of the single good is consumed. At level 1 the maximum consumption for each variant is 1, at level 2 it is 1/2, at level 3 it is 3/8, etc. Within each preferred level the consumption is filled out from left to right, since the consumer prefers to consume e.g. good  $i_1$  up to its maximum before any of good  $i_2$  is consumed.

This extension of the Robinsoniana model with individual binary consumption trees for each species of good presupposes a more advanced trading system than the barter trade described in section 3.4., and it also creates problems concerning the computer implementation. Still, the model is very abstract and “unrealistic”. For instance, it assumes that all the existing variants of consumption goods would ultimately be consumed at very high standards of living. Thus it assumes away the real differences between different consumers. However, the extended model can be useful in suggesting how macroeconomically relevant satiation of demand may emerge in an economy with an overwhelming variety of products.

The basic idea behind the double hierarchy of goods is that demand can be satiated because of a lack of product designs which supports the “next” step in the creation of new diversity with respect to the breadth of consumption although there are lots of unused variety with respect to the average depth or height of consumption. It has always been easier to create variety than diversity, and the increased specialisation of the firms R&D activities as well as the creation of specialised marketing channels is likely to make them even more oriented towards new variants. As the demand for variants beyond the desired

level of the tree was defined above, the firms can even use the introduction of superfluous variants in their competition for market shares (which plays a central role in Robinsoniana). Thus the height of the consumption trees tends to become significantly higher than asked for by the consumers. Increasing the basic-level, diversity is emphasised much less, given the behavioural assumptions of the extended Robinsoniana model.

## 6. Conclusions

This paper has tried to develop an evolutionary model of economic growth and development in a way which allows the discussion of the sectoral and macroscopic consequences of the satiation of demand. Although the model has in several ways been inspired by endogenous growth theory, it has a very different approach. The most obvious mark of distinction is the use of consumer-producer firms and the exclusion of factor markets. The model is also designed to exclude any full endogeneity of growth. Instead it has tried to emphasise the issue of different ways of providing the process innovations and product innovations that allows for long-term growth in relation to a complex structural economic dynamics. In this respect the model can partly be seen as representing an attempt to provide an evolutionary economic micro foundation to Pasinetti's scheme of the structural economic dynamics of a labour economy.

Like the Pasinetti scheme the model deals with an economic system with a varying number of sectors, each of which is producing a consumption good. Consumers have a hierarchy of goods, and they first consume a higher-order good when they are fully provided with the lower-order goods. The goods are produced within consumer-producer firms which organise both production and consumption for their workers. Production takes place by means of labour and knowledge. Through innovative activities firms increase their productivity with respect to individual goods. The long-run consequence of this is that labour becomes available for the production of new consumption goods.

If such new goods are not provided to a sufficient degree, "technological unemployment" will emerge. If there is slow productivity development in the production of new goods, the overall rate of growth will slow down irrespectively of productivity growth in old sectors. Thus, to enhance long-term growth there is a need of "anticipatory R&D", i.e. R&D which produces designs for novel goods in the consumption hierarchy and increases productivity in the production of these goods. However, this is not necessarily done even in economies where we find wide-spread activities on product innovation and process innovation.

This far, the result of the present model (pedagogically interpreted as a "Robinsoniana") fits fairly well with the abstract Pasinetti scheme. But the provision of an

explicit and evolutionary micro founded model in relation to the scheme, and the computer implementation of this model allows for a very large number of research questions. Actually, there seems to emerge of whole new research programme. Two major questions within this programme has been confronted. First of all, there is the problem of specialisation of production and R&D within firms. This problem is characterised by major trade-offs, and a in-depth specialisation presupposes a fairly large degree of economic stability (or government remedies for the consequences of a lack of economic stability). One of the trade-offs concerns the relative emphasis on old and new products and processes. The second question is how we can come beyond Engel (and the simple generalisations of his results) in the development of a theory of demand that is relevant for theoretical and empirical analysis of growth that is characterised by increasing diversity and variety of consumption. The preliminary answers to both questions may indicate the potentials of a bottom-up approach to structural economic dynamics—including the problems of satiation of demand.

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