UNIVERSITÀ DEGLI STUDI DI FERRARA
DIPARTIMENTO DI ECONOMIA ISTITUZIONI TERRITORIO
Corso Ercole I d'Este, 44 – 44100 Ferrara

Quaderno n. 14/2005

April 2005

Patterns of Industrial Development in Costa Rica: Empirical `Validation' of a Firm-Based Growth Model.

Tommaso Ciarli

Patterns of Industrial Development in Costa Rica: Empirical 'Validation' of a Firm–Based Growth Model*

Tommaso Ciarli†

Abstract

The aim of the present work is to join an empirical and a theoretical study in a complementary way. This is done to study the mechanisms of development patterns, concentrating on the issue of industrial development. We first present the results of an in–depth analysis of a small case of industrial development, Costa Rica, in which we study both its micro meso and macro dynamics. Then, we implement an agent based input–output development model, using the micro and meso evidence on the Costa Rican experience to shape crucial functional forms and to parametrise the model. The model then allows us to speculate on Costa Rican development attainments, to analyse the effects of micro–macro interactions, and how they may improve our understanding of general pattern of development.

Keywords: Firm based multi–sector models; technical change; product innovation; vertical interactions; international relations and development; agent–based computational modelling

JEL-classification: C63; C67; L16; O12; O33; O41

---

*A previous version of this paper has been presented at Wild@Ace 2004, Workshop on Industry and Labor Dynamics, The Agent–based Computational Economics Approach, Turin, December 3-4 2004, and a revised version asis forthcoming in the workshop proceedings. The work has benefited from important contribution from both the empirical and the theoretical side. The empirical information used is the preliminary outcome of a study on Costa Rica undertaken within the BID/CEPAL project "El Reto de Accelerar el Crecimiento Economico en América Latina y el Caribe". This study has been undertaken together with Elisa Giuliani who has also collected primary data on the field. We are also grateful to Mario Cimoli, from ECLAC, who has supported the project, financed by the Interamerican Development Bank (IDB), which we acknowledge. The theoretical model is part of an ongoing research in which Marco Valente has a substantial role. Finally, part of the work has been done while visiting the Economic Sciences Department of the University of Bologna, which has provided valid support (thanks to Riccardo Leoncini and Sandro Montresor). All the responsibility for the information provided within the paper is ours and does note necessarily represents the institutions and persons abovementioned.

†PhD. Candidate, University of Ferrara and Birmingham University. Contact address: V. del Gregorio 13, 44100 Ferrara, Italy, `ciarli@economia.unife.it`.

1 Introduction

The aim of the present work is to join an empirical and a theoretical study in a complementary way. The call for complementary studies requires both applying different analytical approaches — which, as for example argued by Nelson (1994a), needs both narratives of specific phenomena and accurate quantitative generalisations — and framing together different levels of economic aggregates that are too often studied 'in a vacuum'. In particular, the latter requires involving in the study both single agents and the institutions in which they act[1].

In this paper we are interested in the analysis of development patterns with a particular attention to industrial development. We thus undergo an in–depth analysis of a small case of industrial development, Costa Rica, studying both its micro meso and macro dynamics. Then, we implement an agent based development model, using the micro and meso evidence on the Costa Rican experience to shape functional forms and to parametrise the model. The model then allows us to speculate on Costa Rican development attainments and to analyse the effect of micro–macro interactions, and how they may improve our understanding of general pattern of development.

In this sense, the title may cause a misinterpretation. The aim is not to undergo an empirical test of the model parameters, or a formal calibration of the model. We implement an 'interpretative' model, we observe the macro results that it generates, and interpret the empirical evidence on aggregate dynamics. Through the 'experiments' of different parameter settings, we use the model to interpret some of the dynamics of the Costa Rican development.

In the next Section 2 we present the methodological approach and the theoretical framework adopted for both the empirical analysis and the theoretical modelling. Particular attention is dedicated to illustrate the purposes of a complementary analysis, starting from the explanatory limits that more orthodox analysis of growth and development present. We do not claim for a particular analytical approach, whether appreciative, formal, micro or macro. On the contrary, we claim that those different perspectives generate an analytical space that need to be considered, concomitantly. The theoretical framework adopted, follows.

In Section 3 we briefly introduce the main results from the empirical analysis on Costa Rica, from both the micro, meso and macro perspectives. The analysis undertaken has required a high number of datasets, instruments, fieldwork, and so on. Here we present the main conclusions of the study, pointing on the elements that are crucial to define or parametrise the model. In particular, strong attention is placed on the innovative and learning activity of the country, and on the relation between multinational firms (MNCs) and the local productive/economic system. In fact, Costa Rica has strongly focused its policy on the attraction of Foreign Direct Investment (FDIs), and in general on the external relations. Our model is well suited to analyse inter firm relations.

The model, illustrated in Section 4, is a micro-based multi sectoral development model, in which firms produce multi–features goods. Each quality feature defines the output, and may induce a different demand. Different qualities are produced via idiosyncratic firms' capabilities, and the use of different inputs. The model entails an input–output structure in which firms in all sectors produce outputs for other sectors and buy inputs from other

[1] Institutions themselves can be analysed at different levels that go from broad "cultural-cognitive" aspects to more specific "normative" ones (e.g. Parto, 2004). Here institutions should be interpreted in the most general way, both as set of norms, and as organisations supporting development, e.g. the components of an Innovation System.

sectors, and/or sell their product to a final market. Firms learn, innovate, choose suppliers, determine quantities, but their result depends on the actions and state of other firms within the same sector, and in upstream and downstream sectors. Even more, they are dependent on the characteristics of the final demand, which is only external — there is only an export market — and the extent to which they match consumers' preferences.

The following Section 5 is then devoted to the analysis of the model results. We first present the general behaviour of the model, exploring a 'benchmark case' with simple and homogeneous parameters, in order to explain the aggregate effects of micro and micro–macro interactions. Then, we undergo different experiments tuning one parameter at a time. In particular, we study those parameters that the empirical analysis have pointed as crucial for the development of the country. Some of the results obtained are quite expected and confirm previous theoretical and empirical evidence. Others are less so.

Finally, Section 6 briefly discusses the results of the simulated experiments in the light of Costa Rican industrial development prospects. Simulated results are used to suggest how the micro and meso conditions observed in Costa Rica may actually affect its development. Thus, the model provide us with a tool to induce the effects of the relations between micro meso and macro dynamics, which are empirically observed but, on which, from the empirical analysis, one may only provide economic intuitions and hypothesis.

2 A premise on the methodological approach and theoretical framework

We can distinguish two main and diametrical approaches to the analysis of development and growth issues: one which calls for 'standard' formalisation, i.e. 'growth theory', and the other one which inquires for the systematisation of qualitative analysis, which we could call 'development theory'[2]. The cross–fertilisation between the two approaches is almost absent (Andersen, 1999; Romer, 1993), but required.

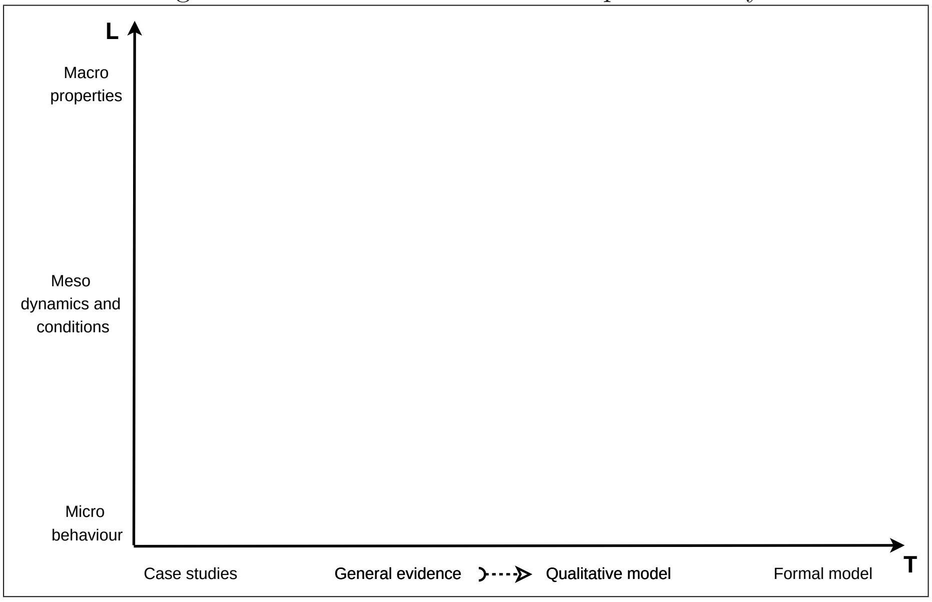
In Figure 1 we provide an interpretative landscape that helps to sketch the differences between the two approaches to growth and development analysis, and the uncovered space of analysis. We indicate on the horizontal axis the type of analysis employed and instrument(s) used, while on the vertical axis we indicate the economic aggregate that is analysed — namely firms and agents (micro), institutions and sectors (meso) and macro entities. The representation in Figure 1 is a simplification that serves for illustrative purposes. No causal relation is assumed between the two dimensions. Nonetheless, two extremes of the space boundaries can be identified. On the one hand in depth analysis of micro case studies, on the other hand formal models of aggregate static or dynamic relations — respectively bottom left and top right in Figure 1.

In this representation orthodox growth theory (both old and new), places on the top right corner[3]. The formal model proposed, while providing fashionable 'representation' of economic growth, has strong limitations in the 'explanation' of economic development. Even when models incorporate elements drawn from the empirical studies, they reach conclusions that do not add much to qualitative research programmes undergone by 'high development economists' such as Hirschman, Kuznets or Myrdal (just to mention some). Conversely, the 'basic heuristics' of the growth models are too constraining, and require

[2]The evolution of the wealth of nations is studied with quite different approaches, analysing quite different objects. These may include classical studies, socio-anthropological disciplines, the National Innovation System perspective, 'high development theory', as referred by Andersen (1999), and so forth.

[3]It can be argued that actually most of the new growth theory is micro founded. Though, the micro foundations refer to a representative agent, an average value.

Figure 1: Two dimensions of development analysis



oversimplifications of the dynamics explored at the empirical level (Andersen, 1999)[4]. As a consequence, the 'incredible' assumptions underneath the models may lead to distorted results, and the too general proxies used, represent what should be explained but is actually squeezed into an indicator.

Conversely, appreciative theorising, for example within the stream of studies that have developed and analysed the concept of National Systems of Innovation[5], covers an area on the left side, along the y axis (Fig. 1). In this approach, peculiar characteristics of the systems usually have a large explanatory power on specific development processes. But it is then difficult to infer on their effect in dissimilar or even incompatible systems. As argued by Andersen (1999), it is then important to represent complex dynamics in a structured form, in order to be able to analyse causal relations and determine possible consequences in a more general setting. In a similar way we can map a number of theoretical approaches to growth and development within the space in the Figure.

Thus, going back to Figure 1 we argue that the analysis of development processes should be undertaken on a wide set formed by the intersection between different types of theorising (and instruments) at different degrees of generalisation, including different levels of the economy: a 'complementary perspective'. In particular, in this paper, on the 'analytical axis' we swing between the origin and qualitative modelling. On the 'level axis' we cover the whole space represented in Figure 1, with a restricted role of the macro level. That is, both empirical and theoretical analysis are undergone considering both micro, meso, and macro entities.

We adopt agent based qualitative simulation modelling and employ the model to provide a number of interpretations on the properties that emerge from the micro interactions. Micro entities and their relational behaviour are conversely drawn from in depth empirical analysis on a particular case study. In fact, from the empirical analysis

[4]Nelson (1994b) and Nelson (1997), among others, indicate a number of drawbacks of the New Growth Theory along these lines.

[5]See Lundvall (1988) Freeman (1988) and Nelson (1988) for preliminary works on the concept of NSI and the seminal projects on the study of different innovation systems in both developed and developing countries in Lundvall (1992) and Nelson (1993).

alone, causal relations between different economic aggregates may not be inferred. It is possible to put forward few intuitions, which can be formally assessed through the outcome of simulations. Thus, the results of the theoretical model provide a valuable tool to analyse the steps of the development process as an emergent property of interacting agents and their reaction to the emergent properties[6]. 'Debugging' of the simulation results allow to inspect the effects of each variable on the system, going somewhat further on the intuitions of the empirical analysis. Finally, results are deemed to be sufficiently robust in the measure in which functional forms and parameters' values are drawn from the empirical case, or from general grounded empirical evidence.

Therefore, the model allows also speculations on the generalisations of the results. That is, using the model as a 'tool', we can analyse different experimental settings (or starting conditions), and infer on their effect on the development process of the abstract economic system represented.

In sum, the simulation model we propose has no predictive power, but only 'analytical power'. It has been not implemented and 'calibrated' to replicate the development of a specific case. On the contrary, it is meant to interpret and generalise the dynamics the specific case shows, adding elements of understanding on processes of industrial development. The reference to a particular experience of industrial development allows to better define functional forms and to restrict parameters space. The collection of both qualitative and quantitative information allows to determine the particular events/entities that hold an important role in the development process. Simulation modelling allows to determine their relevance on the cumulative pattern of development.

Both the empirical analysis and the simulation model follow a structuralist/evolutionary theoretical approach (Dosi, Pavitt, and Soete, 1990). Both the structuralist and the evolutionary frameworks have pursued formal representations of growth and development including results and indications of deeper empirical 'narratives', acknowledging the role of structural changes and path dependency, as central in development processes. The evolutionary representation of growth builds on selection mechanisms, creation of variety through innovation, and competition among the analysed entities (usually, but not always, firms, sometimes sectors, or countries) (Nelson and Winter, 1982). The interaction within the population represented, and the population variance, more than average measures, are at the core of growth processes that are then observed at the macro level as ensuing properties(e.g. Metcalfe, Fonseca, and Ramlogan, 2000). A number of different growth models have been developed, especially since the nineties, which are best reviewed in Silverberg and Verspagen (1995). The structuralist representation draws on development economics, which has provided several interpretations of changes and structural economic and social transformations and their institutions[7]. Authors such as Kaldor (1966) and Pasinetti (1981) have followed the structuralist approach in formalising growth processes. They have pinpointed the crucial role of the demand (both domestic and international), the transformation of the production it may induce, together with changes in investment patterns and the effect on intersectoral relations.

Various authors have called for an effort to tack together elements of evolutionary and structuralist theorising (see for example Verspagen, 2002; Llerena and Lorentz, 2003; Andersen, 1997). Roughly, when combining the two approaches, the evolutionary contribution to input–output models needs to incorporate a deeper representation of interaction across sectors (Andersen, 1994), which goes beyond technical coefficients. Nevertheless,

[6]Also referred to as second order emergent properties (Gilbert and Terna, 2000).

[7]We refer to the second postwar tradition and authors such as Hirschman (1958), Myrdal (1957), Kuznets (1966), to mention really a few.

the common elements between the two 'schools' are various[8]. Cumulative causation, for example, is both referable to Kaldorian/structuralist and evolutionary theories. The understanding of cumulative causation processes helps to explain the increasing differences in development patterns and wealth distribution, therefore to explain development itself[9]. Seen from Kaldor perspective, production induces capital investment, and sectoral specialisation yield to different patterns of demand and accumulation of resources[10]. Demand for manufactures thus induces changes in capital vintages, and increase in productivity. The process generates a multiplier effect on the economy a la Kaldor–Verdoorn law. Seen from Nelson & Winter perspective, dynamic evolutionary processes (such as the ones induced by innovation) are not completely random, they are localised and bound by path dependency (e.g. David, 1992), i.e. they follow non ergodic trajectories (specifically on growth issues see Durlauf, 1993), they are linked to past events, that is to say that they follow a Markov chain process or, simply, that history matters.

Thus, in the theoretical framework adopted, the evolution of demand (both domestic and foreign), plays a crucial role on the development patterns. It determines the evolution of sectors and firms within sectors, and investment in production and technological capacity. The three dynamics — demand, sectoral and industrial dynamics, and investment and technological learning and accumulation — are interdependent. Demand depends on the dynamism of goods on the international market, i.e. their income elasticity[11]. Concomitantly, it is the increase in demand, together with technical change, that may spur the evolution of new sectors, thus of a process of structural change. Given this first co-evolution — sectoral specialisation - demand - structural change (new sectoral specialisation)— the domestic investment is then determined. Investment in new capital vintages, together with different types of learning, improves firms access to the market, and the cumulative causation process takes place. It is then through firms interaction that the ultimate cumulative pattern is determined. Though the economic and institutional system in which firms are embedded plays a substantial role.

Various theoretical contributions have analysed the relation between sectoral specialisation, technical change and demand patterns (e.g. Cimoli, 1994; Los and Verspagen, 2003; Verspagen, 1993; Verspagen, 2002). Some of them are built in the tradition of North-South models a la Dornbush, Fischer, and Samuelson (1997) (e.g. Cimoli, 1994). Others are based on the input–output framework a la Pasinetti (1981) (e.g. Los and Verspagen, 2003; Verspagen, 1993; Verspagen, 2002). Recently few attempts of joining macro structuralist/Kaldorian framework and micro evolutionary framework in the representation of technical change, have been done with a micro based structure, in which the firm

[8] See Llerena and Lorentz (2003) for a comprehensive comparison.

[9] As argued by, among many others, Solomon and Shir (2003) and Solomon and Levy (2003) social wealth follows an autocatalytic process. In fact, several economic phenomena cannot be represented by a 'Normal law' distribution, but need to be represented by 'power law' distributions, such as wealth of people, firms capitalisations, firms size (see citations within the cited references, and Stanley, Amaral, Buldyrev, Havlin, Leschhorn, Maass, Salinger, and Stanley (1996) and Bottazzi and Secchi (2002) on firms' growth rates an size distribution). In brief, an autocatalytic process is characterised by a self–reinforcement of the fittest agents. "The dynamics of a quantity is said to be auto-catalytic if the time variations of that quantity are proportional (via stochastic factors) to its current value." (Solomon and Shir, 2003). Needles to say, given the importance of 'exceptional individuals/events', the representative agent provide no explanation of phenomena (Solomon and Levy, 2003). Empirical 'narratives' crucial to identify such individual/events.

[10] Through the different terms of trade, as put forward by Prebish (1950) and Singer (1950).

[11] The mechanism has been first formalised as the balance of trade constrained growth model by Thirlwall (1979). From both the theoretical and the empirical side, the positive relation between trade specialisation in dynamic goods and growth has been shown by various contribution, e.g. Dosi, Pavitt, and Soete (1990), Cimoli (1994), Cimoli and Dosi (1995), Krugman (1987), Fagerberg (1996), Lall (2000), Dosi, Freeman, and Fabiani (1994), Laursen (2000).

is the main actor, and operates in a context defined by the sectoral specialisation and the regulatory framework (e.g. Dosi, Fabiani, Aversi, and Meacci, 1994; Lorentz, 2004).

We differ from those previous model in two main respects. First, firms competition is based on product qualities instead then on classical measures of quantities with respect to inputs. Thus, the attention is biased toward product innovation, instead then on process innovation[12]. It is in fact the feature of the produced goods that interplays with the final demand and affects the accumulation pattern.

The second main difference is that we propose an input–output firm based development (growth) model — which refines Ciarli and Valente (2004a), by introducing industrial dynamics and endogenising the change in firms' competencies — in which input–output relations are implemented as direct interactions between firms.

3 Main considerations on Costa Rican industrial development: summary of a multi–level case study

In this section we briefly sketch the results of an in–depth empirical analysis on Costa Rican pattern of industrial development, in which the macro meso and micro evolution of the country industrial sector have been analysed[13].

At the macro level, we analyse the extents and effects of the dependency of the country on macro variables, specifically, external demand and macro stability. At the meso level, we explore the institutional context and the main elements of the Costa Rican innovation and learning system. At the meso level, we also analyse the pattern of sectoral specialisation of the country, by way of the changing composition of its exports. At the micro level we investigate the formation of linkages and externalities of foreign direct investors in high technology sectors. We have focused on productive linkages, technological externalities that derive from FDIs, and on the linkages of high technology firms with the NSI. Macro and meso evidence is built through official national and international data. The micro evidence draws on both secondary and primary data. Procomer (the Costa Rican Foreign Trade Corporation), has provided secondary data on the population of firms (60) that operate in Export Processing Zones (EPZs) in the electronic and medical device sectors (EMD). Primary data have been collected on the field in the month of June 2004 among 32 firms operating in the same sectors, with structured interviews. The primary data has been mainly processed with Social Network Analysis, in order to infer on the knowledge relation between firms. The choice of the industries mainly depends on their weight in the country economy.

Costa Rica is known as a successful case of industrialisation[14]. A small country, which has based its recent economic growth on the attraction of foreign direct investments and on the active orientation to exports. In the past two decades Costa Rica has managed to shift part of its export specialisation from agriculture to manufacturing and services, and more recently to high technological devices. And this is said to have been facilitated by the political and macroeconomic stability attained after the 1980s crises, and by the investment in human capital and tertiary education, attained before the 'lost decade'.

The success of Costa Rican growth strategy is quite unambiguous when looking at specific, isolated, elements of the economy, or when considering indicators too aggregate to provide information on the country process of development[15]. Our view, as discussed

[12] Although process plays its role in the determination of the output price.

[13] For a full overview of the analysis implemented and results see Ciarli and Giuliani (2004).

[14] See among others Fox (2003), Rodríguez-Clare (2001).

[15] See for example Moreno-Brid and Pérez (2003) on the balance of trade constraint, Fox (2003) on

in Section 2, is that these contributions offer only a partial perspective on the process of economic evolution of the country. Our theoretical framework, instead, sheds light on different aspects that are less commonly studied by previous analysts and, most importantly, we make an attempt to complement them, providing a preliminary interpretation of the relations between the different levels. Particular attention is placed on the relation between the macro, meso and micro dynamics and the opening process of the country. Structural reforms and trade policies have in fact played a central role in Costa Rican recent development trend, such as in most of the Latin American countries.

From our analysis, in spite of the fact that Costa Rica has achieved remarkable results, it still cannot be fully considered a successful story. As suggested by Lizano and Zúñiga (1999), after the structural reforms, the socio-economic evolution of Costa Rica has been 'not so good, and not so bad'. The results, summarised below, supports this claim[16].

The evidence on macro dynamics shows that the country has maintained an internal stability, with a sustained GDP growth. It should also be noted that the pattern of growth experienced in the period previous to the Mexican financial crisis has not been met in the following two decades. Moreover, the growth cycles tend to be highly unstable due to international price fluctuations and the relevant terms of trade. The low predictable behaviour does not increase the domestic investment ratio. Evidence at the meso level on the National Innovation System shows that Costa Rica is a net technology importer. The country has developed a non negligible human capital endowment, especially at the tertiary level. But this is not fully exploited nor in basic nor in applied research. As most of the Latin American countries, Costa Rica basically lacks a general policy on technological development. As a consequence, we observe a weak national system 'of learning' and almost an absent national system 'of innovation'.

Trade and trade specialisation dynamics suggest the following reflections. The growth pattern of the country strongly relies on exports. Export is strongly related to terms of trade and FDIs investments. International price variations affect especially the domestic industry, and FDI now counts for more than half of the country export value. Conversely, the inducement of a domestic investment demand by domestic exporters and foreign firms is still rather limited in Costa Rica. There is no evidence of a change in the domestic industrial structure toward the sectors that may be linked to FDIs. Structural change is still a matter of foreign players, and only to a limited extent it has occurred at the national productive system. More than a structural transformation the country seems to experience a sudden shift: while FDIs exports concentrate on the high–tech production, the technological content of the local production is still low[17], and does not demand for high level of competencies, R&D, and human skills. In addition, we observe that the income elasticity of the domestic goods is quite low, i.e. the majority of the Costa Rican manufactures compete on price rather then on qualities.

Partially related to what appears as a dualistic development pattern, from the aggregate counts, the effect on the balance of trade is negative, given that FDIs induce more

nominal exports, OECD-IDB (2003) on FDIs flows, and Parrilli (2003) and Bianchi and Parrilli (2002) on the successful policy for Micro Small and Medium Enterprises

[16]For a complete view of the analysis, methodological approach and instruments used refer to Ciarli and Giuliani (2004)

[17]Less then 5% of local exports are classified in the high tech category, and 86% are distributed between comodities (12%), food commodities (30%) and traditional goods (44%). The classification for technological sectors has been develpoed by Hatzichronoglou (1997) and distinguish among low, medium–low, medium–high and high tech. The second classification used distiguishes between commodities, food commodities, traditional goods, durables, automotive durables and technology diffusers. We use an adaptation of Yoguel (2000) on the original classification developed by Ferraz, Rush, and Miles (1992) an Ferraz, Kupfer, and Haguenaer (1996)..

imports than exports. This is coming with an increase in export specialisation, GDP fluctuation, and no generation of fiscal resources, given the particular condition of the trade system under which FDIs operate — Export Processing Zones (EPZ).

In order to provide a more consistent picture, and complement the macro and meso results, we have analysed the direct interactions between foreign and domestic firms. The results of the micro level analysis confirms that the attraction of high-tech foreign direct investments in the country has only partially achieved its developmental goals. First, the innovative activity developed locally by FDIs is limited. Second, although we found evidence of significant co–occurrence between productive and knowledge networks, most of the knowledge flowing between clients and suppliers tend to occur among foreign firms. Third, input–output relations between foreign and domestic firms are limited to 5% of total inputs used by FDIs[18], confirming the limited genration of local demand for investment. Fourth, the micro anlaysis also confirms that the inputs bought locally are mostly traditional goods, which require very low technological effort[19]. The gains are mostly related to the training of skilled workers employed in foreign subsidiaries. This is a field in which the subsidiaries co–operate also with the national institutions. However, for the time being, skilled workers have not yet turned back to the domestic firms and their mobility tends to be limited to EDM foreign firms. Hence, we conclude that the technological externalities generated by FDIs in high tech industries are still too weak. Consequently, the country still lacks the conditions that would allow a reduction of the structural heterogeneity between foreign and domestic firms and across sectors.

Looking at the above information on the country, how can we interpret the process of development from the multilevel perspective? We show the importance of foreign demand and its negative effects on the country stability. We have also shown the limited technological capabilities of the country, which may affect the stagnant industrial transformation. Nonetheless the country is growing. The GDP growth is positive and has been recovering during the 90s. What does this mean for the industrial development of the country? How is the specialisation affecting its development? Is the external demand actually spurring also the investment demand, as put forward within the Kaldorian framework? And is this also spurring learning within the firms, and investment in new, more productive capital? Are firms shifting to better products and acquiring technological competencies? The micro evidence shows that actually export is not spurring investment. The client–supplier relations are not innovative. The institutional framework is only weakly supporting the development of technological capabilities of the domestic firms.

Nonetheless, few questions remain open from the above analysis. The micro evidence collected provide only some suggestions on the pattern that Costa Rica, as an economic system, is probably following. But there is no evidence on how this reflects on the final outcome of Costa Rican development. This is one of the reasons why appreciative theorising needs to be complemented by a more self contained theoretical structure, that manages to link together the different evidences and propose interpretations of the possible scenarios. In the following section we present the model and discuss its results with reference to the Costa Rican experience.

[18]Actually, the measure referes to the inputs bought locally, by the population of EMD firms. Whether they are produced in Costa Rica, or imported by domestic importers is not available from the data.

[19]Data in this case is based on the sampled firms. For the definition of technologiocal classification used see note 17.

4 The model

In this third section we describe a micro–based input–output development model with out of equilibria dynamics. The supply side is agent–based, while the demand side has an aggregate representation and is exogenous. We thus represent an economic system that relates with an external demand, exports. In particular, we design an 'abstract' configuration of a 'local economic system' (LES) in which different firms, pertaining to different sectors, produce different goods across and within them. While the difference across sectors is radical and concerns the final use of the good, the difference within sectors is a reflection of clients' choice, and firms' characteristics. The main features of the model are: i) the production function described in Ciarli and Valente (2004b), which produces the output as a combination of input features and firm specific competencies in moulding them, and represents it as a set of quality features in itself (as in Lancaster (1966)). We substantially implement in a formal way the representation of firms described by Saviotti and Metcalfe (1984) and Gallouj and Weinstein (1997); ii) the representation of an economic system characterised by input–output as firm based interactions; iii) firms' supplier selection among firms producing a good with different quality features; iv) learning by doing and interactive innovation.

The model builds on Ciarli and Valente (2004a) to which we address the interested reader for a more comprehensive description of the structure, behaviour and general results of this previous version. Here we provide a very general description concentrating more on the the model behaviour. A full analytical description of the model is provided in Appendix B.

We maintain most of the features of evolutionary growth modelling. In a dynamic framework, heterogeneous firms search for best routines to undergo the process of production, but in a limited informative structure. The generation of variety occurs as an outcome of learning by doing (deterministic), innovation and entry of firms (partially stochastic). Firms' learning builds on initial competencies. Provided that firms start with heterogeneously distributed capabilities[20], also the learning pattern differs[21]. The selection of firms (exit) is undergone directly by the market with respect to quality features of the produced final good, and its price. Firms are selected by consumers if they sell in the final market, and by clients if they produce intermediate goods.

The model we propose takes into account the fact that in less developed regions such as Latin America, the innovation process is very limited. From the evidence of the Costa Rican case, we induce that the amount of formal innovation undertaken by firms (measured in terms of R&D and patenting), is minimal. Overall expenditure in science and technology activities is well below the developed countries average. Moreover, the great part takes place at the institutional level, and not within firms. Finally, although foreign firms carry more innovation than domestic firms, they seldom develop innovative activities within the country. In a way, we take into account the fact that most of the firms in many developing countries follow a process of acquisition of production capabilities, putting little effort in what Bell and Pavitt (1993) define as 'technological capabilities', the ability to generate and use innovation.

A crucial aspect of the model, is the role of the demand. Demand determines which are the quality features that the firms have to attain, both in the final and in the intermediate market. Thus, demand selects in the market only those firms that, to the knowledge of the buyers best match their preferences. Hence, the demand features have a crucial role in

[20]Competencies and capabilities refer in this paper to the same concept.

[21]Consider that for each input employed, in the basic model configuration, firms need 25 competencies.

explaining the different patterns, in causing growth of the economic system, and defining its industrial composition.

We model the simultaneous decision of the quantity to produce by firms that have input–output relations, through mechanisms of supplier selection and input orders. Those routines entail procedures on quantity variations, exogenous and endogenous stock changes, and a constraint in the variation of input investment and production, consistent with the trivial evidence that firms cannot hire or fire tens of workers from one period to the other. The structure of the relations between firms affects the growth of the represented economic system, depending on the interdependence between the sectors inside the economy, and the need to rely on external inputs.

4.1 Model dynamics: one simulation step

We illustrate the model by describing one simulation step. In each step the entire process of production, input-output relations, sales, innovation and entry/exit is carried. We distinguish among aggregate exogenous dynamics, firm's physical operations (state variables), and firm's behavioural rules (routines).

A number of parameters' and lagged variables' values are set by the simulator — the benevolent dictator governing his small system. Some of the non–stochastic parameters are used for the comparative dynamic analysis[22]. The state of the remaining initial variables are set by an initialisation procedure at time $t = 0$. Initialisation includes: i) a random allocation of input suppliers (Id^{Input}) to each firm for each input bought within the LES; ii) the production of a 'sample' output, which determines quality features (y_m) and price (p) of each firm output; iii) given the sample of the assigned supplier, the information on the input quality features (w_h) and price (p^I) is added before starting the actual production[23]; iv) the level of the final demand is then also determined through the average 'sample' quality features ($\overline{y}_m$); finally, v) given the final demand and the initial quantity produced by each firm, the level of the lagged demand is computed both for firms in the final market and for intermediate goods producers (respectively D and OB). Lagged demand is used by firms to decide the quantity to produce with an adaptive routine.

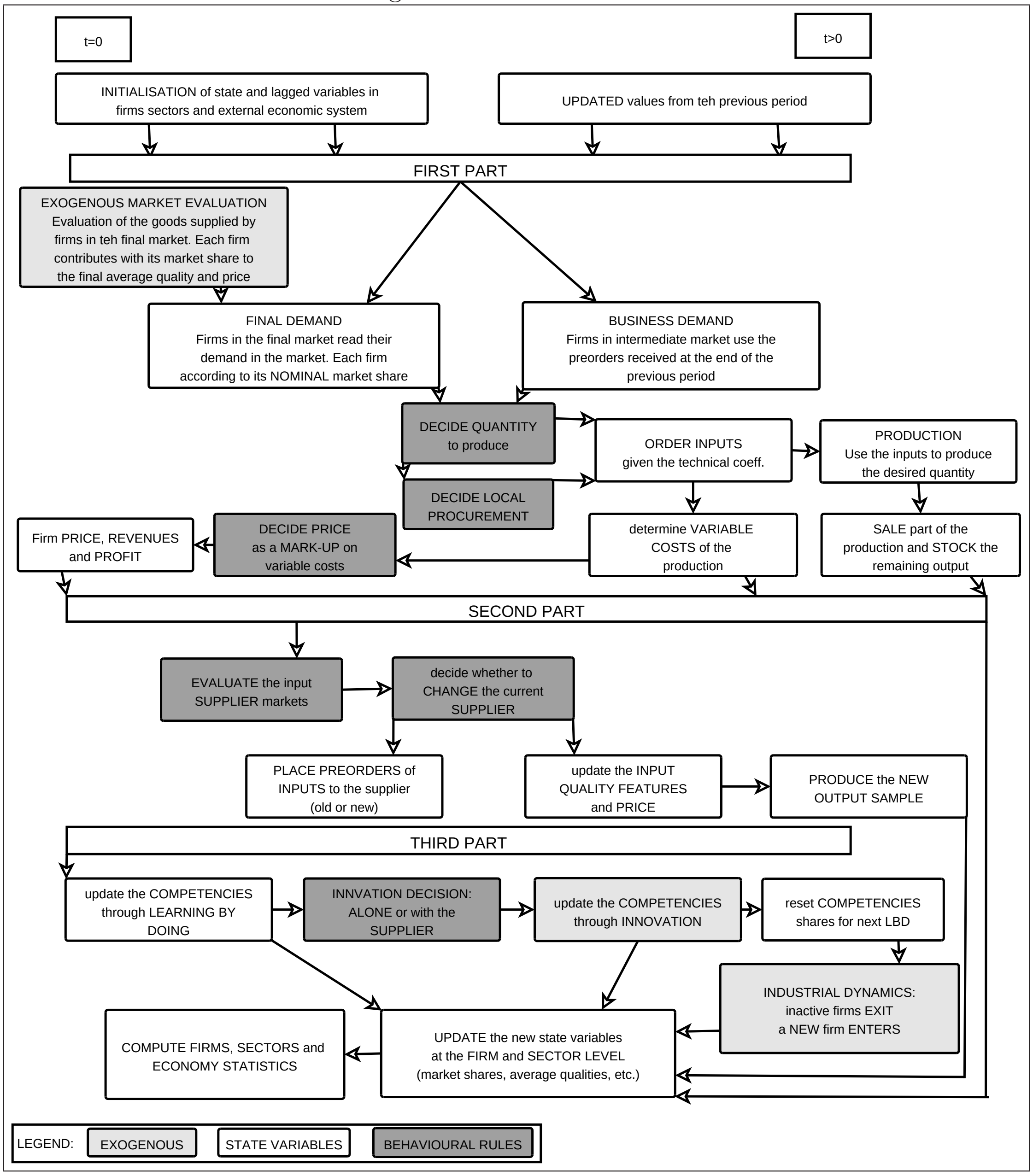
Once all the variables have been updated the next simulation step begins (Fig. 2). The model is demand driven. We represent two types of demand: 'final demand' and 'business demand'. The value of the aggregate final demand depends on the average quality and prices of goods produced in the final market, and on the exogenous preferences of the consumers (α^p and α^y_m respectively for price and qualities). Each firm is then computed a nominal market share (MsV) as a function of its own competitiveness, determined by the relation between its own product quality features and price, and consumers preferences. Thus, the demand for the single firm depends on its own 'product competitiveness' (I) (Silverberg, 1987) and competitors'. Business demand is an outcome of input–output relations, and is thus determined by client firms. After the first period, providers are also chosen on the basis of their product competitiveness[24].

[22] For the specific role of each parameter in the model refer to the analytical description in Appendix B. Description and initial values of lagged variables and parameters are available in Appendix A.

[23] An average value is assigned to quality features and price of inputs acquired on an external market (imported).

[24] We thus assume that demand depends only on the product features, and that the corresponding quantity can be supplied by firms. Firms also do not have production or investment constraint. We assume that resources for investment are available. The reliance exclusively on external demand is not a strong assumption in the representation of a developing country, especially when small. As we have shown, Costa Rica growth depends on its exports.

Figure 2: Model flowchart



Flowchart of one simulation step. In the first part firms undergo the production activity, and in the second part they prepare the production for the following period. In the third and last part competencies are changed, entry and exit take place and finally state variables are updated.

Given the individual demand, firms define the quantity (q) to produce as a variation with respect to the previous period, available stocks, and the long run production. Then, the corresponding amount of inputs needed (qI_k) is ordered to suppliers. The quantity needed of each input is computed through fix technical coefficients (β_k), but buyers may decide to procure locally only one part (lp)[25]. The inputs acquisition also determine the

[25] Given the production coefficients, each firm that buys inputs from the local suppliers, determine the level of the business demand for the current provider. If the input is not produced by local suppliers, the firm directly buys it in a 'general input market', assumed as external from the economic system.

price and quality features of the buyers' output. Quality features of inputs combine with the buyer competencies ($a_{m,h,i}$'s), while the price is set by the buyer as a mark–up (mkp) on the variable costs (c^V). Each firm (both in the final and intermediate sectors) in the meanwhile produces and sells the output. The amount that is not sold increases the stocks (sk). Conversely, if the quantity produced does not meet the demand, part of the stock is sold[26].

Once updated the financial accounts, each firm prepares itself for the following step (day). First, with a random time lag (independent for each input) firms evaluate the current supplier with respect to its competitors (EV). A buyer firm considers to change supplier only when it is loosing market shares, and the current supplier is less performing than average. The best supplier in the market — evaluated according to buyer's preferences — is then selected only if transaction costs (γ) are sufficiently low. In very unstable environments, in which the uncertainty is high, buyer–supplier relations are thus sticky. After the supplier is chosen, the client firm updates the information on the input quality and price features, and informs the supplier on the quantity of inputs he will need in the next period with a pre–order (POB). Finally, the firm produces a new sample product for the following period.

The choice of the supplier is a crucial aspect of the model, as it contributes to determine the competitiveness of the buyer firm, and this mechanism percolates and multiplies through the input–output structure. Therefore, all firms of the LES contribute to various extents to the level of the final demand, the system pace of growth. The possibility for each buyer (in whatever sector) to choose its suppliers, generates a selection dynamic which should tend to increase the average of goods' quality features produced within the LES.

In the model we assume that the governance power is strongly biased toward the buyer firms; suppliers may not search for clients. Nonetheless suppliers can signal themselves through their output features. This assumption is not realistic in general, but is not that unrealistic when considering the relations between FDIs and domestic firms. In the Costa Rican case, domestic firms do not have any power in searching for clients among MNCs. On the contrary, MNCs decide quite arbitrarily their suppliers[27].

The model includes learning and innovation at the firm level. Both induce an increase in firms' initial competencies. Learning ($\hat{a}$) is a deterministic process, which follows a logistic form, increasing with the total quantity produced, proportional to the initial competencies distribution within the firm. That is, firms tend to increase their competitive advantage and learn more where they already have higher capabilities[28]. Learning halts either when it reaches the maximum value (z) for an input used, or when the input supplier is changed. Only in the latter case the learning curve starts again from the beginning.

The distribution of initial capabilities though may change as an outcome of innovation ($\tilde{a}$), which is stochastic, and changes the distribution of the learning process from the following period. We assume that only the firms in the final sector may innovate and this takes place at a random rate (τ^I), with a random intensity[29]. Nonetheless, with a

[26] Note that this may occur for various reasons: the quantity pre–ordered by buyers is different from the actual orders, loss or gain of buyers, exit or entry of firms, relative improvement of buyers' product competitiveness, and so forth. The complex interdependent structure of the input–output process, renders the quantity forecast always erroneous, in the short run.

[27] For more general evidence see Gereffi and Kaplinsky (2001), Gereffi (1994), Giuliani, Rabellotti, and Van Dijk (2005), Quadros (2002).

[28] There are different reasons that may explain this cumulative pattern of competencies, such as the role of absorptive capacities, and the specialisation of the firm on strategic competencies.

[29] Between $\tilde{a}^{max}$ and $\tilde{a}^{min}$. The assumptions made here are again in line with the evidence collected

given probability $(1-\iota)$ the firms in the final market involve the supplier in the innovation process. In this second case, innovation is an outcome of the interactive process. In both cases we acknowledge the fact that the innovating firm may collect some information on consumers preferences, and accordingly address the innovation toward a specific group of competencies (not to one specific competency though).

Finally, at the end of the period, firms that have not sold any good for a certain time lag (τ^{Ex}) exit the market. Similarly, in each sector, a new firm enters the market at a random rate (τ^{E}). The features of the new firm are mainly drawn from a normal distribution centred on the average values of the market. Suppliers are randomly selected, and the initial quantity produced is computed on an expected demand, which depends on the total demand for the sector, and on the market concentration (proxy for entry barriers)[30].

Once firms and market operations are completed,market and firms value are updated at the initial stage for the following simulation step. In our model a time period is a short production period, that may be equivalent to a day/week.

The model has been implemented with Laboratory for Simulation Development (LSD) platform[31]. Simulations, debugging, data analysis and representation have been produced within the same LSD environments.

5 Simulation results: model behaviour

In the present section we first show 'general' results of the model using a 'basic' benchmark configuration, in order to analyse the model's behaviour and the effect of the main parameters. Following, we test different experimental settings, through which we analyse the prospects of Costa Rican development.

5.1 The benchmark configuration

In the benchmark configuration we represent an economic system composed by three sectors pertaining to the LES and one sector tied to the external market. The first sector is initially composed of 3 firms, the second and third ones of 10 firms and the latter of 5 firms. The system has a 'circular' structure, i.e. intermediate sectors sell their output to sectors from which they also buy an input[32](Figure 3). Firms in the intermediate sectors use two inputs, while in the final sector they use three inputs. The firms in the first sector buy one input from an external market, and firms in the final sectors, sell their output only to the external market.

Despite the high parametrisation of the model, in this configuration sectors and firms are initialised quite homogeneously, in order analyse few key determinants (parameters)[33]. In particular: i) firms do not innovate; ii) both final consumers and firms have homogeneous preferences on goods quality features and prices (all α's are equal to 1); iii) sectors differ

on Costa Rican firms: very low Science and Technology (S&T) expenditure in the Costa Rican private sector, and a small amount of local innovations by MNCs, which acquire innovations from the headquarters (exogenously).

[30]For a specific description of each parameter and state variable initialisation see equation B.4.2 in Appendix B.

[31]For further information see the website (`http://www.business.auc.dk/Lsd`), Valente and Andersen (2002), and Valente (2002).

[32]A 'linear' system is one in which sectors can be ordered along a theoretical linear input–output structure, where a 'first' and 'last' sectors can be identified.

[33]see Table 2 in appendix for the complete set of parameters' values

Figure 3: Structure of the economic system in the benchmark configuration: Input–Output relations

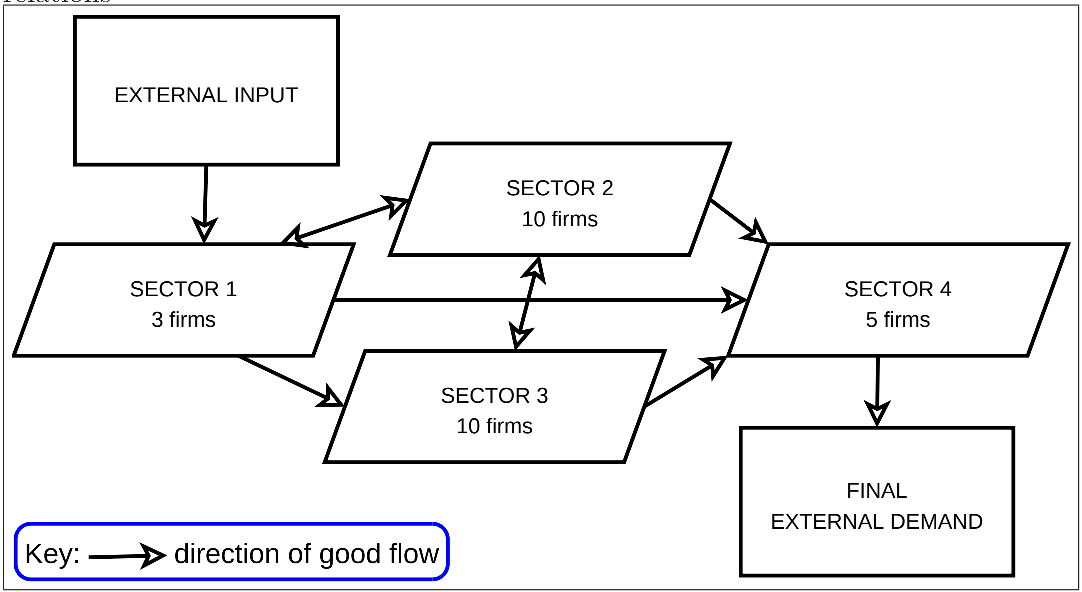


Figure shows the input-output relations between the different sectors of the system, each one represented by a parallelogram; inputs are represented by arrows. Sectors 1, 2 and 3 use two inputs each; sector 4 uses three inputs.

by the initial quantity produced, the entry rate of firms and input technical coefficients (higher for the final sector); iv) finally, firms differ by competencies, supplier choice time lag, and initial supplier (all randomly drawn)[34].

Figure 4 shows the aggregate output of the LES (hereinafter the GDP of our virtual LES) as an average of 10 simulation runs with different initial seeds[35]. The first result that we obtain is that the micro dynamics modelled produces a pattern of sustained, although not significantly increasing, growth. With respect to Ciarli and Valente (2004a), in which endogenous growth is sustained only for a limited number of periods, a negligible process of learning[36], causes an increase in final goods' quality features that overwhelms the increase in goods' prices. Endogenous growth is thus sustained by embodied product innovation. The effect of the change of product quality features is more evident in the initial years[37]. The rate of growth is higher due to the percolation of quality features induced by the input–output process. In fact, at each step of the production chain, firms embed into the output their competencies. Suppliers evaluation and selection reinforce the mechanism.

The aggregate pattern is better ascertained looking at the de–trended rate of growth in Figure 4[38]. The initial high rates are followed by a period of low growth, and only around the half of the simulation the rate of growth increases again. This second wave of growth

[34]Nonetheless, it should be noted that including only those three firm initial differences, implies a number of other idiosyncratic characteristics that derive from the model structure itself, such as the quality of inputs, their prices, the final demand, i.e. all the initial variables and parameters that are set by the initialisation procedure (see Section 4.1, i.e. all values 'Init' in Table 2).

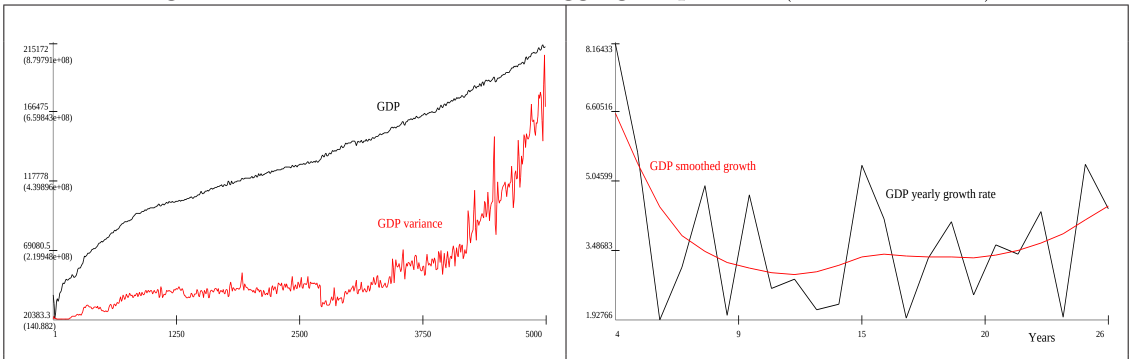
[35]Where not differently specified, all following results are presented as an average over 10 simulations.

[36]The rate of growth of LBD is $zg = 2e^{-006}$ and the maximum value it can achieve $z = 0.1$

[37]One year is assumed to equal 180 periods.

[38]Figure 4.b includes an estimation of the trend of growth rates isolating the cycles, using the filtering procedure suggested by Hodrick and Prescott (1997). In brief, given a time series $y_t = g_t + c_t$ ($t = 1, \cdots, T$), where g_t is the growth component and c_t the cycle, the authors assume the latter are deviation from the trend, with zero mean. They thus minimise the cycle terms as following:

Figure 4: The benchmark case: aggregate pattern (GDP evolution)



(a): GDP (with cross simulation var.) (b): GDP growth (with smoothed trend)

Box (a) shows GDP pattern and its cross simulation variance (values into parenthesis on a $y2$ axis). As confirmed in box (b) where the rate of growth is shown, GDP grows initially, when the input–output of qualities increases substantially the output features through inputs acquisition, slows down and achieves higher rates subsequently, when the LBD has more effect. The increasing variance of growth across simulation runs suggests that aggregate results depend strongly on the micro interaction.

is due to the firm learning process. It is the result of a smooth increase in the quality of inputs procured by each supplier (through competencies increase) or of a discrete shift that follows a change in a firm's suppliers, or, from the change of a firm's supplier suppliers, and so on. The final extent depends on the vertical structure of relations.

The second result that we obtain is that small changes in the random process of supplier selection and decision timing, may yield to quite different outputs. Figure 4.a shows that the variance of the growth pattern across simulations is high and increases though time, as differences cumulate. It should be noted that most of those random differences are due to incomplete information. With full information since the beginning, firms would be able to maximise their output by choosing the fittest supplier, by choosing the best learning strategy, and so on.

Going back to the causes of increase of the aggregate output, Figure 5.a shows the pattern of average sectors qualities. Although the average value cuts off peaks, the most significant changes in final demand are observed when radical changes in input qualities occur due to new entrants, or a successiveness of supplier changes[39]. The effect multiplies across the input–output relations.

The meso level outcome is shown in Figure 5.b. The evolution of the sectors' concentration, measured with an inverse Herfindahl index (IHI)[40], confirms the above discussion on growth patterns.

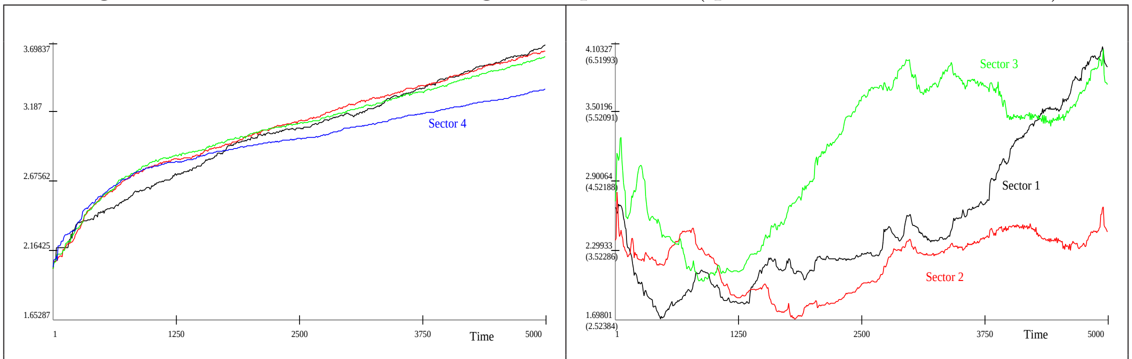
Initially, in the intermediate sectors only the best firms survive, improving the average quality features of inputs (mapped in the initially higher rate of growth). After a sufficiently high number of periods new entrants achieve to erode from the incumbents shares of the market. While in the first period of adjustment the dynamics of the three markets

$Min_{\{g_t\}_{t=-1}^{T}} \left\{ \sum_{t=1}^{T} c_t^2 + \lambda \sum_{t=1}^{T} [(g_t - g_{t-1}) - (g_{t-1} - g_{t-2})]^2 \right\}$ There is no clear consensus on the value of the smoothing element λ to be used for non quarterly data; following Maravall and del Río (2001) we apply $\lambda = 10$.

[39] Results available from the author.

[40] The IHI tends to one when the market is totally concentrated in one firm, and to the number of firms in the market, in the case of 'perfect competition'. We start the simulation with 3 firms in the first sector, and 10 firms in the second and third sectors, but the entry exit process changes the population number. Therefore, the scale also changes (scales of second and third sectors is within parenthesis).

Figure 5: The benchmark case: general patterns (qualities and concentration)



(a): Average quality of output features (b): Inverse Herfindahl (per sector)

Box (a) show the increasing pattern of goods' quality features; the lower growth in the final sector is due to the lower quantity produced. Box (b) depicts the market concentration, measured with an inverse Herfindahl index. Given the different number of initial firms, sectors 2 and 3 are depicted on the second vertical axis ($y2$) — values within parenthesis. In all sectors, on average, there is first a strong selection process, then the new entrants diversify the market, although the extent differ widely across sectors.

seems uncorrelated, in the latter part of the graph they follow similar paths. Given the strong interaction among the sectors this is easily explained.

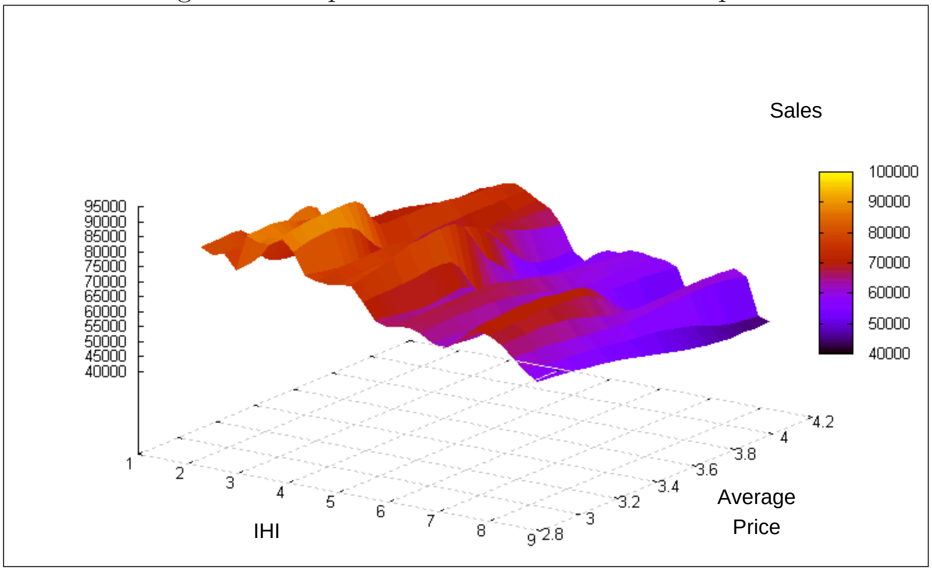
As shown in Figure 6 output tends to be higher when the market moves to an intermediate concentration value. This is the case when, after inefficient providers have been selected out, new entrants are enough competitive to erode entrant barriers, and compensate transaction costs. As expected, sales also tend to increase when the average price lowers. It is more puzzling the result that price and market concentration seem inversely related.

The puzzle is explained by the fact that firm have no price strategy. Hence, providers that supply input at a lower price are preferred, *ceteris paribus*. Conversely, the market concentration directly affects the final sales. Given the final demand, firm in an oligopolistic market produce more than in a competitive market, increasing also the pace of learning, hence their competencies. This cumulative process may halt when incumbent firms maintain a conservative attitude toward supplies, while entrant firms choose new, more competitive suppliers. The final outcome is only observable, and not preventable. The complex interaction may yield to any particular result. For example, leading firms my demand a sufficiently high quantity, which allows its suppliers to follow high patterns of competencies cumulation, and maintain a reduced gap with respect to entrants.

The cumulative pattern of learning is depicted in Figure 7, with respect to the quantity produced and the market share moving average of each firm (data refer to the last simulation step). As expected, quantity, market share and learning follow an autocatalytic process: an increase in the quantity produced induces an increase in learning, and may reflect (depending on the other firms) in an increased market share. The increase in competencies through learning is then likely to increase even more the quantity produced — both due to selection and to the increase of the final demand that each supplier firm hastens. Thus, initial small differences induce large gaps between firms' performance.

While the relation between quantity and learning is assumed, it is interesting to understand how learning affects output quality features and the final market share. This is what is shown in Figure 8, for both the final (a) and the intermediate sectors (b). In the final sector, given that firms respond directly to the final demand, the relation is almost

Figure 6: Output market concentration and prices



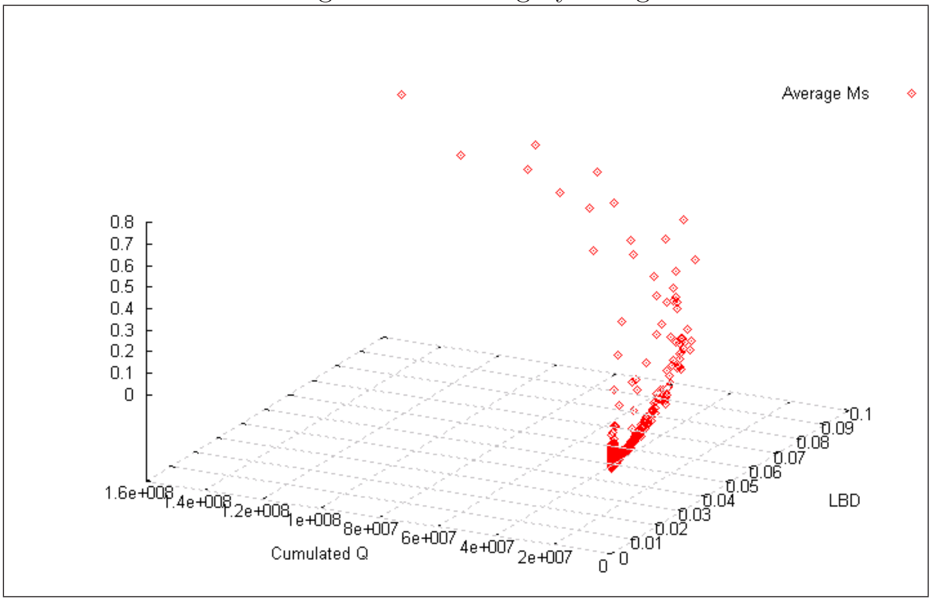
The figure depicts the relation between total sales, average price and market concentration in the three intermediate sectors. On the vertical axis, total sales of the sectors are shown. On one axis of the plane average sectoral price are represented, and on the other the concentration index. i) Total sales and price are negatively correlated; ii) total sales and concentration are positively correlated; and iii) sectoral concentration and average price are also negatively correlated.

linear: firms' market share is positively and linearly related to the average quality feature of the produced good. Quality on its own depends on learning patterns but is not the only element. In fact, the relation between learning and market share, in the final sector, is negative, although in a non linear way. This result is though quite illusory, and is explained by industrial dynamics, and the systemic innovation that it induces. While firms in the market learn (not all in the same way), new firms enter imitating the average market value for each competence. Therefore, when they enter the market, they have high competencies, although they still have not undergone any learning. Conversely, in the intermediate markets, the complex formation of their demand, which is characterised by strong path dependence, reduces the clear and linear relation between the three variables to a weaker results, although in the same direction. In fact, a number of firms with a quite different output, attain a similar result on the market. Given that this 'cloud' results by comparing a number of simulations, the reasons by which they attain similar market shares, within the same or different sectors, may be various.

5.2 Experiment I: product specialisation

A number of theoretical and empirical contributions have shown the relevance of the sectoral specialisation in the process of development, as it has been put forward in Section 2. The empirical analysis on Costa Rica has shown that there has been a limited sectoral upgrading of the domestic industry, while FDIs have concentrated the trade specialisation toward technological intensive and dynamic goods. The relation between the income elasticity of the external demand and the internal product specialisation in our model is proxied by the relation between the quality features of the output and the demand preferences of the consumers. The model has been configured with 5 quality feature per each good. In the benchmark configuration both price and quality elasticities where unitary. In this

Figure 7: Learning by doing



The figure shows the increasing pattern learning by doing with the increase in the cumulated quantity produced (on the plane), and their relation with the average market share in the final period.

experiment we simply randomise the 5 quality elasticities for both final and intermediate buyers, leaving all the other parameters identical (included price elasticity). Preferences may assume a value between 0 and 2, drawn from a Uniform distribution. Thus, the average of the final demand preferences is the same as for the benchmark case (see Table 3 in Appendix). Different results need to be explained only with the heterogeneity of consumers and client firms

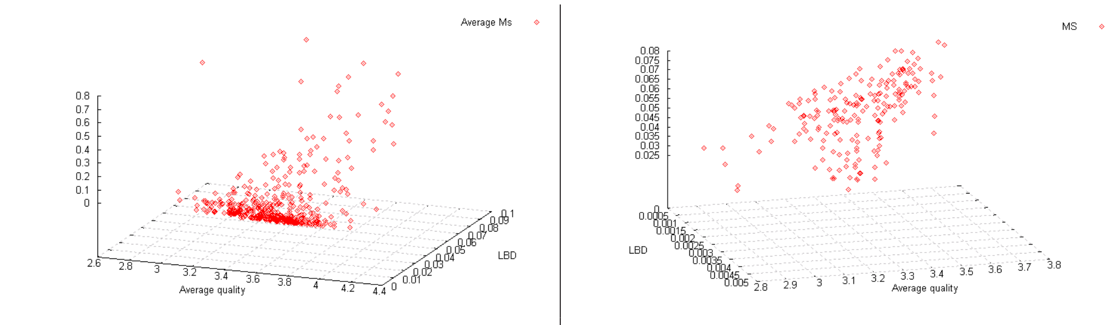
How do different elasticities and market preferences relate with a heterogeneous firms? In order to be able to compare the aggregate results of this first experiment with the benchmark case, we first show the micro to macro interactions. We first compare quality features and price effect on the firm market shares (cross firm comparison in the final step). Results shown in Figure 9 are in line with the empirical evidence that explains Leontieff and Kaldor paradoxes. High average quality products lead to higher market shares, almost irrespective to price. As for the benchmark case, due to the linear form of the demand, the result is much neater for firms in the final sector (b) than in the intermediary ones (a).

In the final market firms with the higher price are the ones that sell more. The figure shows only a bunch of firms with 'defensive' attitude, that achieve to maintain a fair position in the market, without matching the final demand quality requirement, but competing on prices. In the intermediate sector case, although the positive relation between quality and market share is non liner, it is much more evident than in the previous benchmark case (see Figure 8)[41]. In the intermediate sector two relative maxima appear: one in which firms are characterised by an average–low price, and high qualities, and a second lower maxima in which high pricing firms produce high quality goods.

At the meso level we compare again the relation between the IHI total sales and prices. Once more, we obtain the result that final sales are quite neutral to differences in the output price. Comparing Figure 10 with the benchmark case (Figure 6), it shows that the price effect is lower when allowing for heterogeneous preferences. The market

[41]See also Figure 24 in Appendix C to compare the single observations

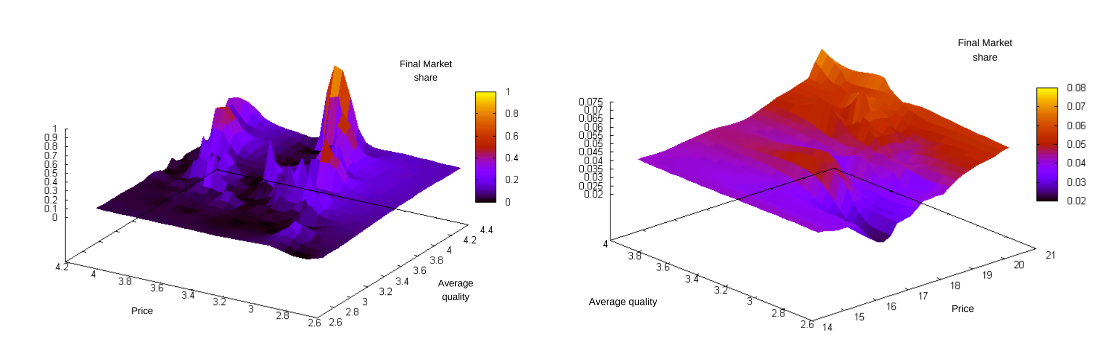
Figure 8: The effect of LBD on output quality features and market shares



(a): Intermediary sectors (b): Final sector

The figure shows the relation between the final market shares (vertical axis), learning and the quality of output (plane). Box (a) show the cross simulation results from the intermediate sectors, box (b) from the final sector.

Figure 9: Heterogeneous preferences: quality and price features on market shares



(a): Intermediary sectors (b): Final sector

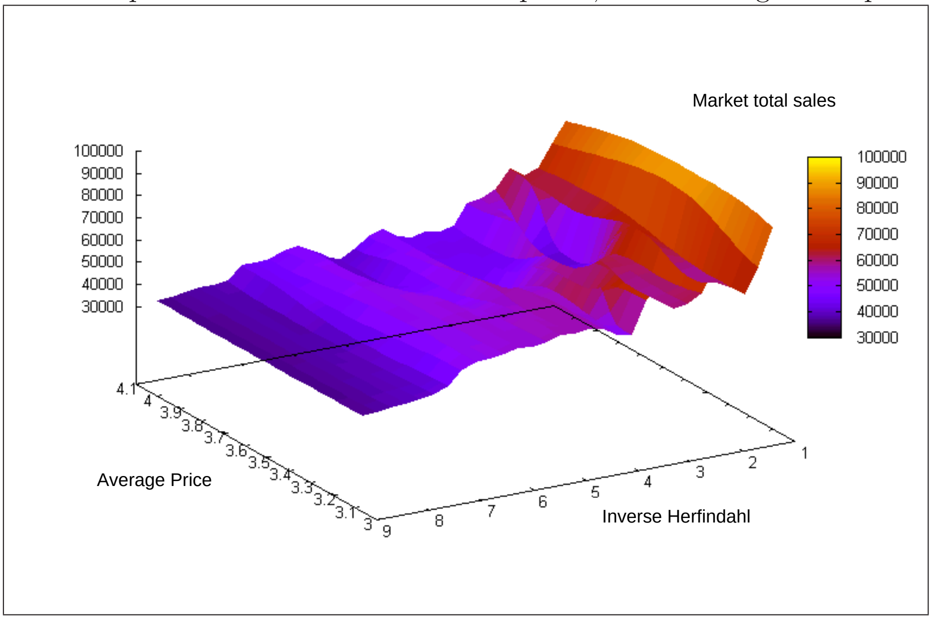
The figure shows the result of a cross simulation comparison where the firms' market share (vertical axis) in the final period ($t = 5000$) is related to the average quality and the price of their output. Results for intermediary sectors in box (a) and final sectors in box (b).

concentration maintains its positive relation with the final output (due to learning), and in this case it is neutral to prices.

Let us now compare the effect of heterogeneous consumers and client firms preferences on aggregate output. The aggregate output growth is higher when the market has homogeneous preferences (11).

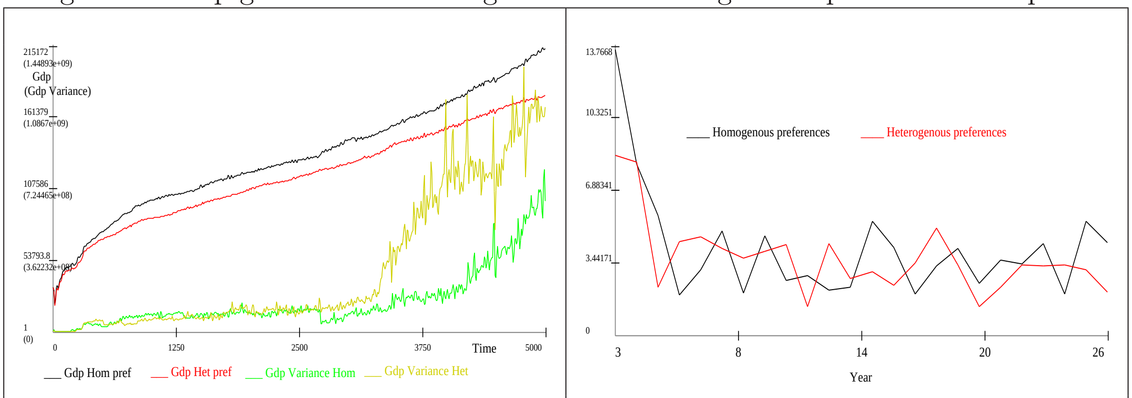
This result depend on the micro and meso mechanisms shown above. In brief, assuming homogeneous preferences (benchmark configuration), the LES is able to meet the market requirements quite easily, and the pattern of specialisation has no role in determining the final demand. Things differ when the entire system seeks to meet the final consumers preferences, through the overall input–output process. Given that each buyer has its own capabilities in undergoing production, and its own perception of the preferences of its own market — final or intermediary — it is much more unlikely that all the preferences throughout the process are met. We clear this out with an example: say that the final consumers prefer quality features 1 and 2. Some of the final firms are better endowed then others with their competencies, to meet higher standard in quality features 1 and 2. Call them firms A and B. Now, both A and B have their own preferences with respect

Figure 10: Output market concentration and prices, with heterogeneous preferences



to the inputs' quality features, which need not be the same of the consumers. Each firm selects a particular supplier, which produces an output with the required features. If A and B select quality features 3 and 4 to be competitive, they struggle to meet consumers' preferences. The same applies to their supplier, and so on.

Figure 11: Gdp growth with heterogeneous and homogeneous preferences compared

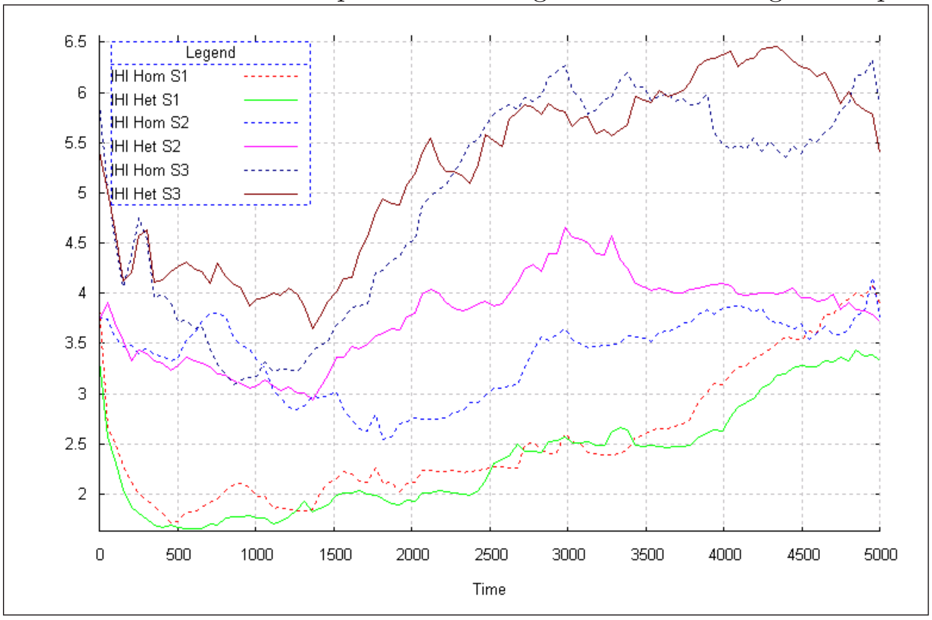


(a): GDP trend & variance compared (b): GDP growth rates compared

Once more, the absence of perfect information shows the differences with respect to a system in which a representative consumer with known preferences acts as a unique demand (as in the benchmark configuration). The higher variance shown by the configuration with heterogeneous preferences, suggests that in some simulations firms are randomly assigned the 'right' preferences. We will came back on this in a moment.

Less predictable is the result on the market concentration. We would expect that a higher variability in the clients preferences would allow a higher number of firms to survive in the supplier market. At a first glance the results that we obtain from the simulation is that the concentration patterns are quite similar in the homogeneous and heterogeneous cases (Figure 12). This result may be explained by the fact that the IHI of the different sectors are correlated. In fact, with heterogeneous preferences if one sector concentrates on a low number of firms, the variance of quality features demanded by that sector to the suppliers also reduces, and only a few supplier may match those features. The others are then selected out. Consider the above example with firms A and B. Now suppose that only firm A survives in the market and becomes a monopsonist. The firms in all the supplier markets are no more chosen on the base of a distribution of quality features, but on a single preference. Consequently, within the supplier sector the firms that respond to the monopsonist request are more likely to survive, becoming themselves monopsonist, and so on.

Figure 12: Sector concentration patterns: homogeneous vs. heterogeneous preferences



In the figure we compare the market concentration in the intermediate sectors (S1, S2 and S3) in the homogeneous (dotted lines) and heterogeneous (full lines) preferences cases.

Figure 12 shows that IHI in the different intermediate sectors — solid curves — follow a very similar pattern. The pattern is quite similar also for dotted lines — representing IHI in the homogeneous case — but to a much lower extent, given that they also intersect. The same evidence is confirmed by the pairwise correlation between the average IHIs of the different sectors[42]. Table 1 shows that in the case of heterogeneous preferences the correlation between IHIs of different sectors is significantly higher than with homogeneous preferences.

We now go back to the aggregate output variance and show the importance for a LES to move toward sectors highly dynamic in the world market. In fact, figure 13 shows that once the demand conditions are met, the overall economy shows a rate of growth consistently higher than the average growth attained in any of the two settings (homogeneous and heterogeneous preferences).

Analysing and 'debugging' the micro process that undergo the successful aggregate series, reveals the importance of both deterministic and random mechanisms, and explains some of the micro and meso mechanism that drive to the final aggregate result. First, through time buyers select those suppliers that produce an input with the quality

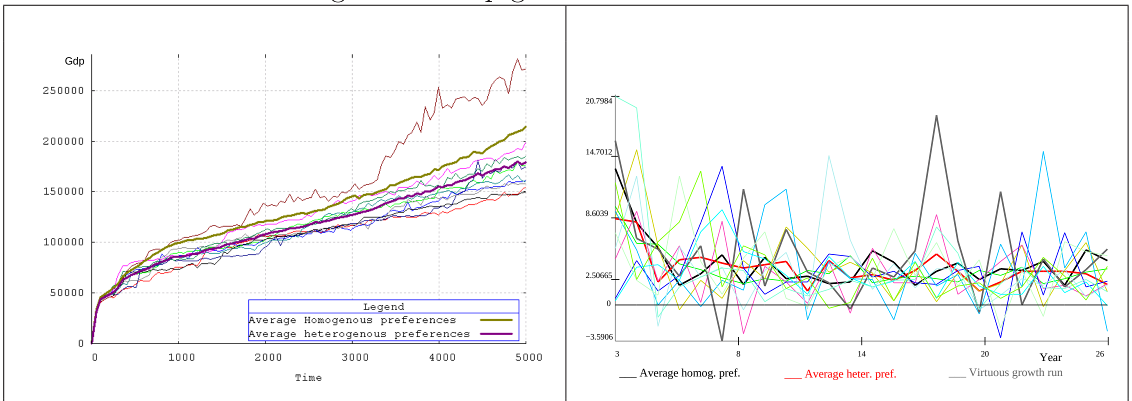
[42]We have estimated the correlation between the variables also using no parametric procedures — both Spearman's and Kendall's correlations — with very similar results.

Table 1: Pairwise correlations among different sectors' concentration

	Homogen. preferences			Heterog. preferences		
	S1[a]	S2	S3	S1	S2	S3
S1	1.0000			1.0000		
S2	0.5861*	1.0000		0.6442*	1.0000	
	0.0000			0.0000		
S3	0.6363*	0.3969*	1.0000	0.8269*	0.8579*	1.0000
	0.0000	0.0000		0.0000	0.0000	

[a]S# stands for the number of the sector
Note: an * stands for significance at 5% level

Figure 13: Gdp growth: a successful case



(a): GDP compared (b): GDP growth rates compared

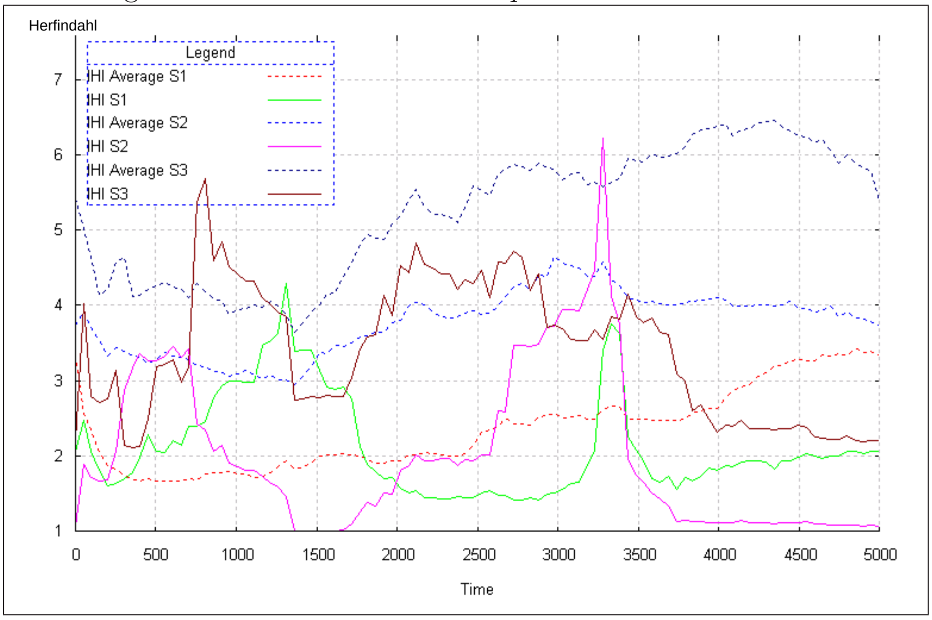
The figure compares the 10 different simulations with heterogeneous preferences with the averages of both homogeneous and heterogeneous preferences (thicker lines). The aggregate output of one single simulation run with heterogeneous preferences clearly outperform the two average values.

features that are highly elastic in the final demand (given that in this successful case they have guessed the preferences). Second, this selection creates temporary monopolies in all intermediary sectors, inducing high rates of learning, especially in the second sector. Third, monopolists exploit their position and cumulate competencies up to the maximum level[43]. Fourth, few new entrants are still able to erode market shares. As portrayed in Figure 14 the second sectors moves from a monopolistic condition ($t = 1500$) to a highly competitive one ($t = 3300$). Fifth, the loss of the dominant position induces the incumbent firm in the second market to change both suppliers in a short time span, finally looking for better inputs. Given the high level of the incumbent's cumulated competencies and its product specialisation, the firm regains in few time periods almost the complete market. As it may be noted by comparing the timing in Figures 13 and 14, this change causes the radical shift in the growth rate and pattern.

To conclude with this first experiment. First we have confirmed the importance of specialising in the production of highly dynamic sectors. Second, allowing for a very simple and basic heterogeneity and a limited information structure, we have shown how they may change the results in a number of respects, and especially how they may point to different factors of growth (the relevance for policy implications is evident). Finally, we

[43]The assumption of a maximum level of learning with the same supplier acknowledges the importance of variety and the need to absorb knowledge from different sources.

Figure 14: Sector concentration patterns: a successful case



In the figure we compare the average IHI with heterogeneous preferences, with the successful simulation run.

have shown the relevance of 'reconstructing' explanations from the micro behaviour to the macro emergent properties.

5.3 Experiment II: disembodied innovation

In this second experiment we introduce also disembodied innovation, as an outcome of internal R&D or external acquisition. Determining the process of innovation is an extremely complex task, that may affect the results in different ways. Given the application of our model, we assume that innovation is mainly an exogenous transfer, endorsed by the the evidence of the Costa Rican case. In the next experiment we discuss the role of 'interactive innovation'. Both cases of homogeneous and heterogeneous preferences are illustrated. Initialisation parameters values included in the innovation process are shown in Tables 4 - 5 in Appendix A.

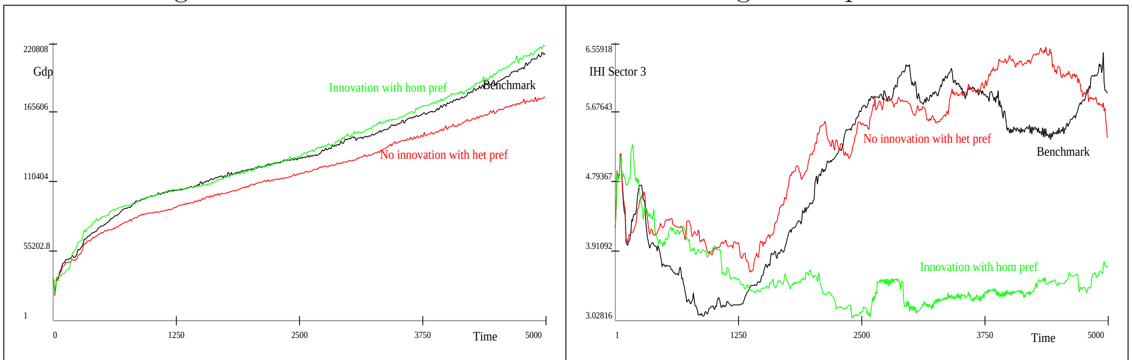
5.3.1 II.a homogeneous preferences

Adding a simple process of quasi–exogenous innovation to the benchmark case with homogeneous preferences does not produce astonishing results. As one may expect, the economy grows more, due to the higher increase in the quality features of the output (Figure 15). Nonetheless, the difference in the aggregate output growth are on average quite weak, although the variance is higher due to the random feature of innovation.

More interesting is the effect that small innovations in product features generate at the meso level, on the market concentration. Figure 15.b shows the significant difference of average IHIs in the third sector, between the benchmark case, the first experiment (heterogeneous preferences and no innovation), and the innovation case[44].

[44] Although the effect on the third sector is the more marked, the direction is the same in the other intermediary sectors (Figure 25 in Appendix C).

Figure 15: The effect of innovation with homogeneous preferences



(a): GDP compared (b): IHI compared

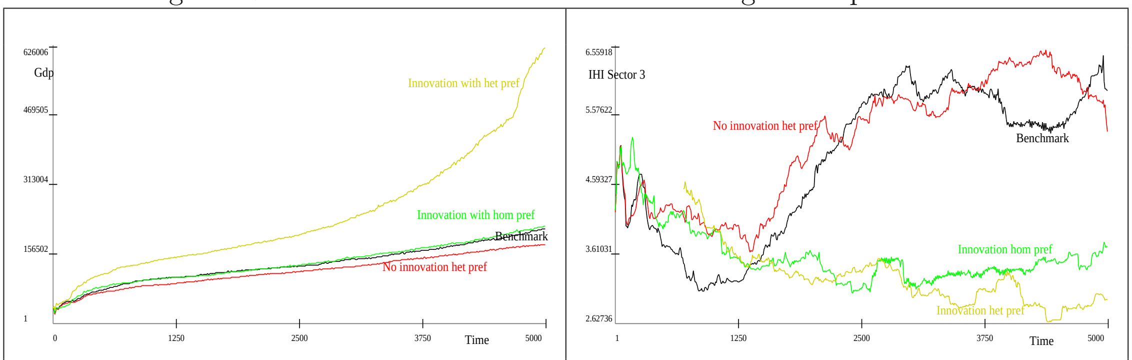
This increased market concentration suggests that the interactive innovation between foreign firms in the final sector, and domestic suppliers, may create a polarisation within the intermediate sectors. That is, in the absence of horizontal spillovers of knowledge and competencies, the domestic firms linked to the foreign firms exclude the other domestic suppliers from the market, causing heterogeneity within sectors.

5.3.2 II.b: heterogeneous preferences

We then introduce heterogeneous preferences of consumers and clients within the same parametrisation used in 5.3.1[45].

Again, the results are quite predictable. We expect to observe a higher aggregate growth with respect to the same configuration without innovation (Experiment I). In fact this is the case, but with an aggregate growth that is much higher than in the previous case of innovation with homogeneous preferences (Fig. 16.a).

Figure 16: The effect of innovation with heterogeneous preferences



(a): GDP compared (b): IHI compared

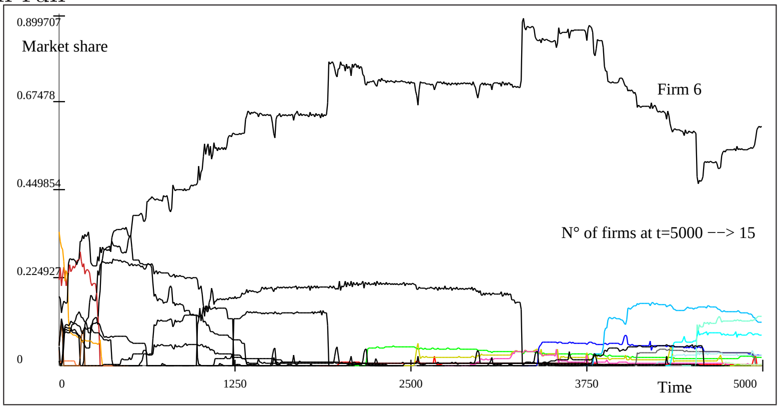
Two main reasons explain those results. First, again the 'lucky' initialisations, in which firms correctly perceive the final preferences. Second, actually firms play an active role in shifting toward the pattern of production that is demanded. As described in Section 4.1 innovation is consumer oriented. When the supplier is also involved, it also improves on the 'right' competencies reinforcing the final result.

[45] As in Section 5.2, the parameters are set in order that the average of preferences, over the different quality features, is the same of the homogeneous case, in order to allow a close comparison (See parameters in Table 5 in Appendix A).

In brief, the results of this experiment settings show that the shift toward a product specialisation that seeks higher quality elasticities — without caring about prices that in this configuration grow more than in all other experiments, affect consistently the overall development of the system. Needles to say, the usual feedbacks shown in the previous section, on embodied technological change and cumulation of competencies, are increased.

Nonetheless, the effect of innovation on market concentration is the same, if not stronger, than with homogeneous preferences (Figure 16.b and Figures 25 – 26). Only few 'lucky' firms participate to this high growth pattern. We then observe the industrial dynamics across the different sectors, and in the different simulation runs. In the most common case, one of the firms that starts from the beginning, or enters in the early periods, ends by dominating the market even when it looses market shares for a long period (see for example Figure 17).

Figure 17: Industrial dynamics in sector 3 with innovation and heterogeneous preferences: one simulation run

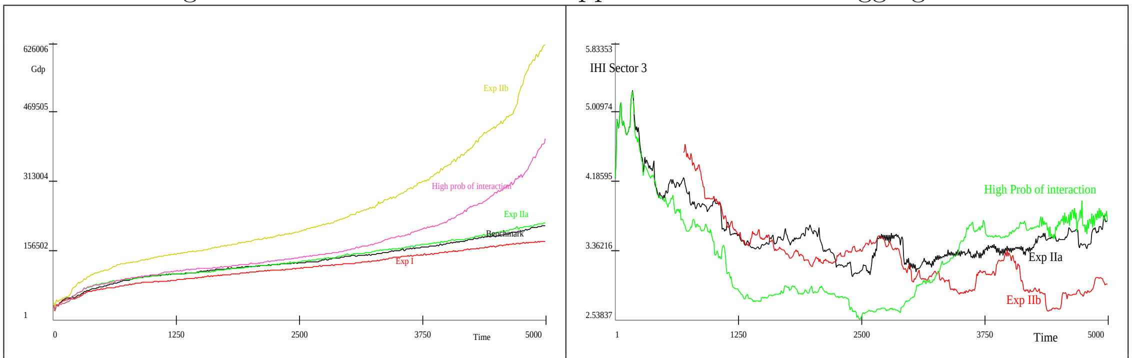


5.4 Experiment III: increasing user–supplier interactions

The relevance of user–supplier interactions in the innovation process has been shown in various contexts and industries. Freeman (1988) and Lundvall (1988) provide a clear explanation on the mechanism of learning and innovating by interaction. Richardson (1972) argues that collaborative relations in various areas of firms' activities is at the core of industrial organisation. The literature on industrial districts, clusters, local and regional system of innovations, industrial networks and *milieux innovateurs*, describe theoretical and empirical justification for vertical collaborations. One of the main arguments put forward is that the interaction between client and supplier in the design of input and output features may increase substantially the quality of the final output, its insertion in the the process of production, and the process itself. In a way the supplier adapts its innovation activity to the client requirements, and viceversa provides the client with information on technical improvements.

The structure of international relations is quite different. The north–north relations between firms may entail knowledge transfer and cumulation, while the relation north–south are often purely productive (e.g. Markusen and Maskus, 1999). The analysis on the multinational firms in Costa Rica has confirmed the evidence on north–south relations. Innovation in loco is very scarce, and definitely not interactive. Knowledge transfer is limited to the minimum necessary for a standardised production, and when possible avoided by choosing only sufficiently efficient firms. In order to interpret the effect of small changes in the relational structure that involves innovation procedures, we 'experiment' what happens when the firms in the final sectors are keen to innovate together with local suppliers. That is, we increase the probability of involving the supplier, from 0.5 to a random number between 0.75 and 1[46]. The remaining parameters are set as in the benchmark case (homogeneous preferences).

Figure 18: The effect of client–supplier innovation on aggregates



(a): GDP compared (b): IHI compared (third sector)

The results shown in Figure 18.a confirm the theoretical and empirical intuitions on the positive role of user–supplier relations in innovation processes. The effect of interactive innovation on the quality of goods produces a strong increase in the aggregate growth attainments. At the meso level, as explained above in section 5.3.2, the same process induces an increasing structural heterogeneity among firms, polarising the system between high standard suppliers and 'regular' suppliers. The effect is strongly rooted in the initial condition of the market, i.e. on which suppliers are initially selected by innovating firms. The same effect occurs in all sectors (Figure 27).

5.5 Experiment IV: local procurement

The final experiment we run explores the involvement of domestic suppliers in the production process of the MNCs in the final market. That is, how much input the firms in the final market buy from local producers. Once more we use the evidence from Costa Rican data on local procurement to infer the percentages. We thus assume that firms in the final market buy only between 2% and 12% of their input from the local intermediary sectors[47]. In order to render the results comparable with the previous ones, we leave the same three intermediary sectors and we add an external input market that supplies the remaing inputs to the final sector (Figure 19).

Coherently with the information on Costa Rica on the technological content of the goods acquired locally, with respect to the ones imported, we acknowledge that imported goods have a higher quality. We run simulations with both homogeneous and heterogeneous preferences, and comment the resulting output together[48].

The first result that we obtain is quite expected, given the multiplier effect of input coefficients: a significant reduction in the growth patterns with respect to the previous results (Figure 20.a).

[46]See Table 6.
[47]See Table 7 for the experiment complete change in paramterisation.
[48]As usual, the average income elasticity on qualities in the final market is the same, 1 for homogeneous preferences case, and 1.006 for heterogeneous case.

Figure 19: Structure of the economic system with reduced local procurement: Input–Output relations

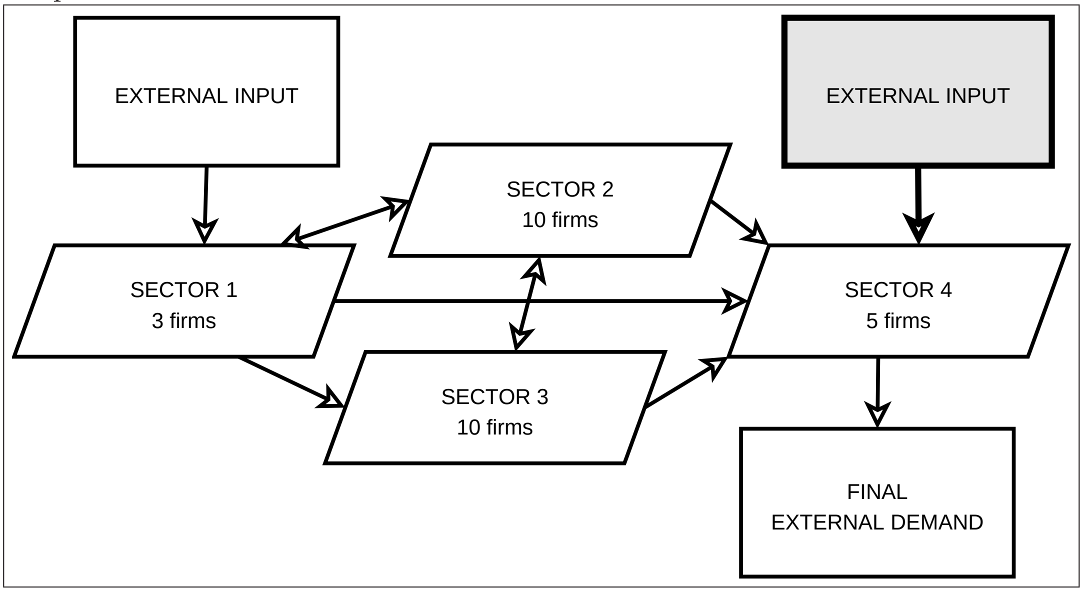
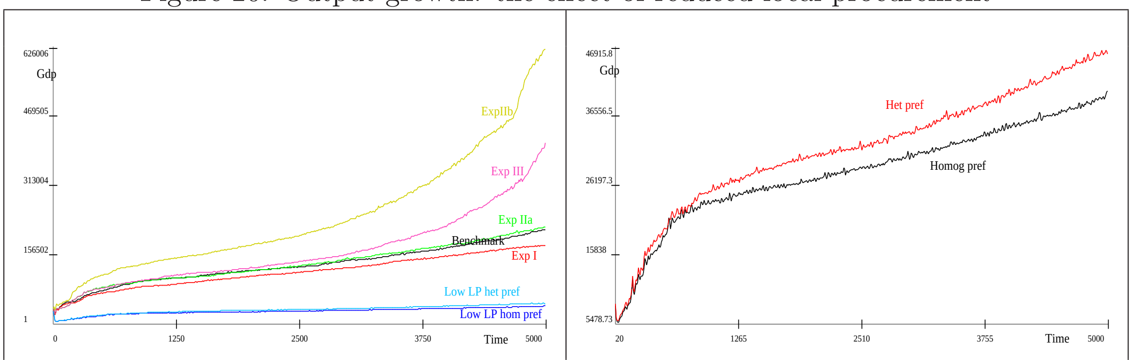


Figure shows the input-output relations between the different sectors of the system, each one represented by a parallelogram; inputs are represented by arrows. Sectors 1, 2 and 3 use two inputs each; sector 4 uses four inputs: the three intermediary sectors and an exogenous one.

Compared with the other settings, the growth attainment seems quite poor, although one should consider that the growth rates depicted in Figure 20.b are not that far from the observed ones — on average around 3% assuming one year lasts 180 periods, and exclundign the first periods of rapid growth.

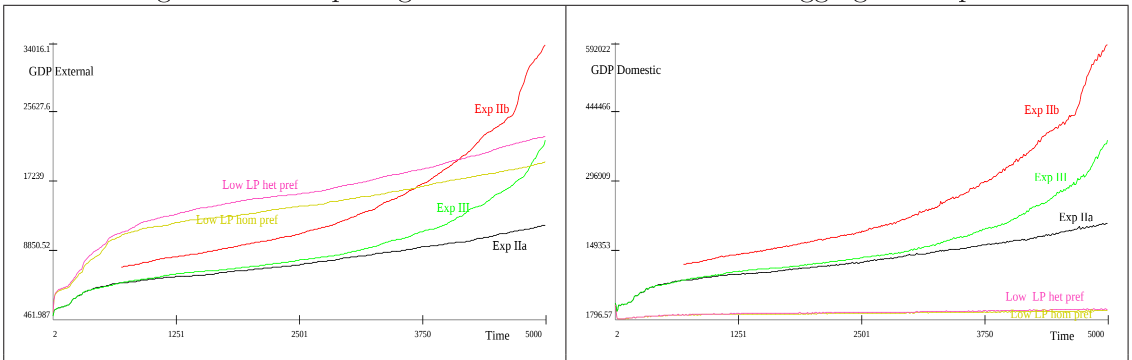
Nonetheless, if those results are consistent, one would then ask why a MNC would prefer to invest in Costa Rica, if the final growth is so poor compared to a LES in which it is easier to innovate, local procurement is higher, feedback from suppliers, also, and so on (i.e. all the other patterns of aggregate growth in Figure 20.a). Figure 21.a provides a preliminary answer to this question. The aggregate output of foreign firms grows much more since the beginning, due to the use of the better imported inputs. Only after a large number of periods, MNCs within the other systems simulated above, achieve to catch–up. Needles to say, the other face of the coin is that the domestic GDP is much lower with

Figure 20: Output growth: the effect of reduced local procurement



(a): GDP compared in all settings (b): GDP with low local procurement respect to the previous cases, and the gap with the other systems increases (Figure 21.b).

Figure 21: Comparing domestic and external firms aggregate output

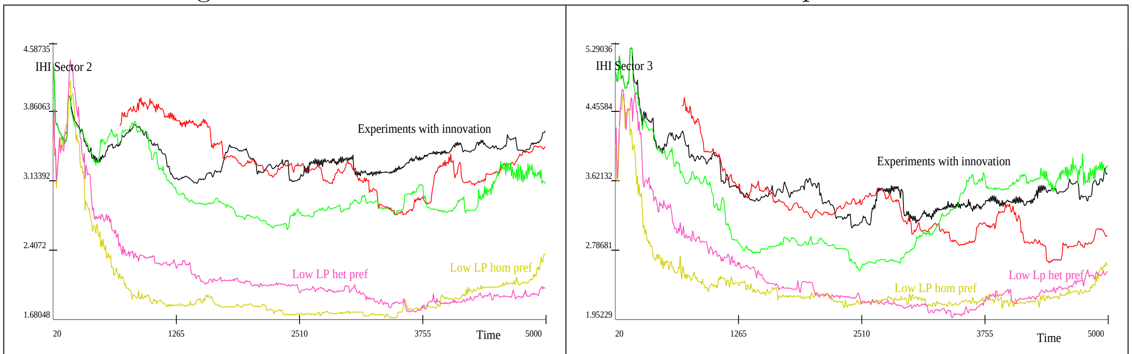


(a): External firms aggregate output (b): domestic firms aggregate output

The reason that explains those results should be quite straightforward by now. The external aggregate output, initially higher for firms that import their inputs, is reached by economic systems in which external firms buy all their inputs locally, because they spur the local learning and innovative process. Therefore, the qualities embodied in local inputs increase. Then, also the interactive innovation yields to higher results with high local procurement. Alternatively, the final firms have to rely on exogenous inputs' qualities, only.

The reason why the domestic grow is so poor is even more straightforward. There is though one further result at the meso level that may be interesting to mention. In this configuration with marginal involvement of local firms in the industrial process, intermediary sectors get even more concentrated than in the previous configurations with innovation (experiments II and III) (Figure 22). Apparently, the reduced extent of the market, increases even more the advantages of the firms with which buyers exchange knowledge. In fact, the learning dynamic is much lower, implying that the interactive innovation provides a higher relative advantage to the suppliers involved.

Figure 22: Market concentration with weak local procurement



(a): IHI sector 2 (b): IHI sector 3

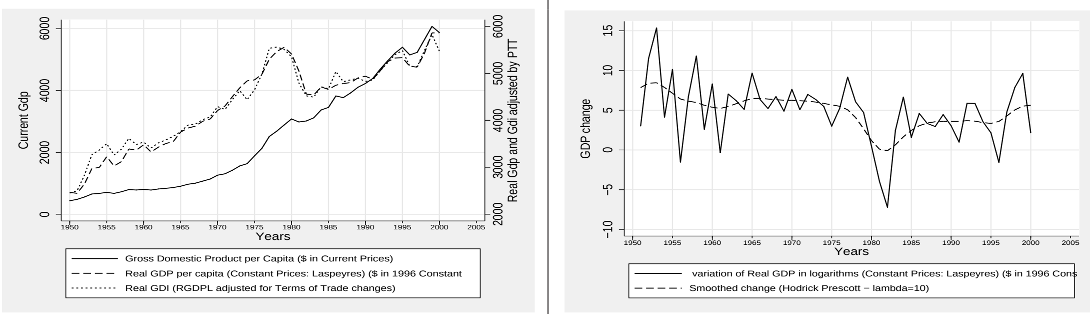
Thus, when the local network is so poor, it is likely that the heterogeneity among local supplier is further increased.

6 Final considerations on Costa Rican pattern of development

The paper we are concluding has been an attempt to put together appreciative theorising and qualitative modelling, using simulation tools. The results of an analysis conducted at the micro, meso and macro level of the Costa Rican industrial development have been used to refine a firm–based multi sector development model. Conversely, the model, after explaining its general behaviour has been used to analyse some of the evidence of the Costa Rican development experience. The model analysis has been undergone both to check its general validity, and to interpret some of the Costa Rican results.

The GDP growth attained by Costa Rica (Figure 23) can be 'interpreted' with a number of aggregate growth patterns produced by the model (see for example Figures 20, 13, 4). By no means this implies that any of the pattern simulated with the model matches with, or 'replicates' the real ones. For example, we have no control for the Mexican crisis that in 1980 causes the drop of GDP growth, and which affects the following development. Although it can be exogenously introduced, as explained in Section 2, it would not add much to our analysis. Our aim is to interpret and explain development patterns, generalising from particular stories.

Figure 23: Costa Rica growth patterns



(a): GDP and GDI growth

(b): GDP rates of growth

In brief, if our model, micro based on the empirical experience, does not replicate its aggregate outcome, it means that we may be missing some important variable, or we are not well 'calibrating' the model. Still, we are able to show how given micro and meso conditions (observed) interact and produce given emergent properties. This is what we seek to do with this first study. The following considerations may then be drawn from the results obtained.

With experiments I and IIb — respectively sections 5.2 and 5.3.2 — we show that the shift to product specialisations with higher income elasticity (more dynamic on the international market), guarantee a virtuous development pattern, when the LES has a circular structure. The comparison between the two experiments (I and IIb) shows that when firms' innovation activity is addressed to this shift, growth attainments change radically . Without any innovative effort and only path–dependent learning, it is only a matter of 'luck' whether the economic system enters the virtuous path. From the empirical point of view, we have seen that Costa Rica has made this shift, through the attraction of FDIs. The recently established firms produce commodities that are dynamic on the international market, and keep incorporating innovations exogenously developed by the headquarters. So far so good, but the weak 'learning' national system and the weaker national innovation system, are not promising in spurring the needed innovative efforts.

With experiment III — Section 5.4 — we have then shown that the LES represented gains a large advantage from the interactive dimension of innovation. Involving the suppliers in the change of product features and of the competencies to attain them, produces extremely positive results even when the demand is inelastic toward quality features. From the empirical point of view, we have seen that in Costa Rica this process is extremely weak . First, there is very little innovation that is carried on within the country, in local laboratories. Second, the knowledge relation with suppliers is only sporadic. There are few differences between the simulated and the real systems. First, in Costa Rica it is a one shot transfer and not a replicated process. Second, it is not an interaction process, which may produce new capabilities from which both firm gain, but an exogenous transfer. The weakness of interactive innovation hampers the possibilities of local development. So far, less good. A low interactive process doe not generate changes in product specialisation in domestic firms, i.e. domestic firms maintain production with low income elasticity of export demand.

The above is related with experiment IV — Section 5.5. We have shown that the limited involvement of the local industrial sector in the production process of exporting firms, hampers dramatically the growth of the system. In dynamic terms, the result is even more evident, as the limited local procurement reduces the accumulation of capabilities through learning, and increases the heterogeneity within sectors, inducing high market concentration. The evidence on Costa Rica is clear on the fact that the average use of local inputs from the most advanced sectors (EMDs) covers only a very small percentage of required inputs. The simulation results show that the limited growth does not affect the output of the final sectors, at least in the short period. Nonetheless, it strongly reduces the prospects of development of the domestic industry. In fact, in Costa Rica the increase in FDI has induced a quite high rate of GDP growth, but this remains a concern of foreign firms. The single INTEL has contributed in 1999 to 60% of the GDP growth (Rodríguez-Clare, 2001). Our simulation results confirms the increasing gap between domestic growth and external growth when the local procurement is so limited. Moreover, the empirical evidence clearly shows that the export specialisation of the domestic industry has not changed in the last decade. The country keeps producing non dynamic goods, with a limited technological content. As shown in the simulations, this is a result of reduced local innvoation, almost absent interactive innovation, and the limted involvement of the local industries.

The results from the simulations suggest that this pattern does not yield to a sustained development and growth path of the domestic industry.

References

Andersen, E. S. (1994): "Innovative Linkages and Systems of Innovation," Working Paper 1994-6, Department of Business Studies, University of Aalborg.

——— (1997): "Escaping Satiation in an Evolutionary Model of Structural Economic Dynamics," in *Escaping Satiation: Increasing Product Variety, Preference Change and the Demand Side of Economic Growth*, Max Plank Institute for Research into Economic Systems, Jena.

——— (1999): "Multisectoral Growth and national innovations systems," *Nordic Journal of Political Economy*, 25(1), 33–52.

Bell, M., and K. Pavitt (1993): "Technological Accumulation and Industrial Growth: Contrast Between Developed and Developing Countries," *Industrial and Corporate Change*, 2(2), 157–210.

Bianchi, P., and M. D. Parrilli (2002): "Small and Medium–Sized Enterprises: A Comparative Approach to Latin America and the European Union," Quaderni del Dipartimento 26/2002, Dipartimento di Economia, Istituzioni, Territorio, Universitá di Ferrara.

Bottazzi, G., and A. Secchi (2002): "On the Laplace Distribution of Firms Growth Rates," LEM Working Paper Series 2002/20, Laboratory of Economics and Management SantAnna School of Advanced Studies.

Ciarli, T., and E. Giuliani (2004): "Structural Reforms and Structural Change in Costa Rica. Industrial Dynamics, Structural Heterogeneity and Linkages: The Role of FDIs," in *BID-CEPAL seminar 'El Reto de Accelerar el Crecimiento Economico en America Latina y el Caribe*, ed. by M. Cimoli, and D. Tietelmann, CEPAL, Santiago del Chile.

Ciarli, T., and M. Valente (2004a): "Explaining Development Patterns through Interactions between Local and International Systems," Discussion paper, DRUID Summer Conference on "Industrial Dynamics Innovation and Development", `http://www.druid.dk/conferences/summer2004/`.

——— (2004b): "A Generalised Computational Model of Firms Production and Interactions: Emergent Network Structure and Industrial Development," in *Industry and Labour Dynamics. The Agent -based Computational Economics Approach. Proceedings of the Wild@Ace 2003 Conference*, ed. by M. Richiardi, and R. Leombruni. World Scientific Publishing, Singapore.

Cimoli, M. (1994): "Lock–in Specialization (Dis)Advantages in a Structuralist Growth Model," in *The Dynamics of Technology Trade and Growth*, ed. by J. Fagerberg, B. Verspagen, and N. von Tunzelmann. Edward Elgar, Aldershot.

Cimoli, M., and G. Dosi (1995): "Technological paradigms, patterns of learning and development: an introductory roadmap," *Journal of Evolutionary Economics*, 5, 243–268.

David, P. A. (1992): "Path-Dependence and Predictability in Dynamic System with Local Network Externalities: a Paradigm for Historical Economics," in *Technology and the Wealth of Nations*, ed. by D. Foray, and C. Freeman. Pinter Publishers, London.

Dornbush, R., S. Fischer, and P. A. Samuelson (1997): "Comparative Advantage, Trade and Payments in a Ricardian Model with Continuum of Goods," *American Economic Review*, 67(5), 823–839.

Dosi, G., S. Fabiani, R. Aversi, and M. Meacci (1994): "The Dynamics of International Differentiation: A Multi–country Evolutionary Model," *Industrial and Corporate Chance*, 3(1), 225–241.

Dosi, G., C. Freeman, and S. Fabiani (1994): "The Process of Economic Development: Introducing Some Styilized Facts and Theories on Technologies, Firms and Institutions," *Industrial and Corporate Chance*, 3(1), 1–45.

Dosi, G., K. Pavitt, and L. Soete (1990): *The Economics of Technical Change and International Trade*. New York University Press, New York.

Durlauf, S. N. (1993): "Nonergodic Economic Growth," *Review of Economic Studies*, 60, 349–366.

Fagerberg, J. (1996): "Technology and Competitiveness," *Oxford Review of Economic Policy*, 12(3), 39–51.

Ferraz, J., D. Kupfer, and L. Haguenaer (1996): "El Desafío Competitivo para la Industria Brasileña," *Revista de la CEPAL*, 58(LC/G.1916-P)).

Ferraz, J. C., H. J. Rush, and I. Miles (1992): *Development, Technology and Flexibility: Brazil faces the Industrial Divide*. Routledge, London, New York.

Fox, J. W. (2003): "Successful Integration into the Global Economy: Costa Rica and Mauritius," Research report, USAID.

Freeman, C. (1988): "Japan: A New National System of Innovation?," in *Technical change and economic theory*, ed. by G. Dosi, C. Freeman, R. R. Nelson, G. Silverberg, and L. Soete. Pinter Publishers, London.

Gallouj, F., and O. Weinstein (1997): "Innovation in Services," *Research Policy*, 26, 537–556.

Gereffi, G. (1994): "The Organization of Buyer-Driven Global Commodity Chains: How US Retailers Shape Overseas Production Networks," in *Commodity Chains and Global Capitalism*, ed. by G. Gereffi, and M. Korzeniewicz. Praeger, Westport.

Gereffi, G., and R. Kaplinsky (eds.) (2001): *The Value of Value Chains: Spreading the Gains from Globalisation*, vol. 32 of *IDS Bulletin*. IDS, University of Sussex, Brighton.

Gilbert, N., and P. Terna (2000): "How to Build and Use Agent-Based Models in Social Sciences," *Mind and Society*, I(1), 57–72.

Giuliani, E., R. Rabellotti, and M. P. Van Dijk (eds.) (2005): *Clusters Facing Competition: The Importance of External Linkages*. Ashgate, Aldershot.

Hatzichronoglou, T. (1997): "Revision of the High-Technology Sector and Product Classification," OECD, STI Working Papers 2, OECD.

HIRSCHMAN, A. O. (1958): *The Strategy of Economic Development*. Yale University Press, New Haven.

HODRICK, R., AND E. C. PRESCOTT (1997): "Postwar Business Cycles: An Empirical Investigation," *Journal of Money, Credit and Banking*, 29(1), 1–16.

KALDOR, N. (1966): *Causes of the Slow rate of Economic Growth in the United Kingdom*. Cambridge University Press, Cambridge.

KRUGMAN, P. R. (1987): "The Narrow Moving Band, the Dutch Disease and the Competitive Consequences of Mrs. Thatcher: Notes on Trade in the Presence of Dynamic Scale Economies," *Journal of Development Economics*, 27, 41–55.

KUZNETS, S. (1966): *Modern Economic Growth: Rate, Structure and Spread*. Yale Uninversity Press, New Haven, CT.

LALL, S. (2000): "The Technological Structure and Performance of Developing Country Manufactured Exports, 1985-1998," QEH Working Paper Series 44, Qween Elizabeth House, Oxford University.

LANCASTER, K. J. (1966): "A New Approach to Consumer Theory," *Journal of Political Economy*, 74, 132–157.

LAURSEN, K. (2000): *Trade Specialisation, Technology and Economic Growth: Theory and Evidence from Advanced Countries*. Edward Elgar, Cheltenham, UK.

LIZANO, E., AND N. ZÚÑIGA (1999): "Evolución de la Economía de Costa Rica durante el Período1983-1998: Ni Tan Bien, Ni Tan Mal," Discussion Paper Documentos 2, Academia de Centroamerica.

LLERENA, P., AND A. LORENTZ (2003): "Alternative Theories on Economic Growth and the Co–evolution of Macro–Dynamics and Technological Change: A Survey," LEM Working Paper Series 27, Laboratory of Economics and Management, Sant'Anna School of Advanced Studies, http://www.sssup.it/~LEM.

LORENTZ, A. (2004): "Sectoral Specialisation and Growth Rate Differences Among Integrated Economies," LEM Working Paper Series 06, Laboratory of Economics and Management Sant'Anna School of Advanced Studies.

LOS, B., AND B. VERSPAGEN (2003): "The Evolution of Productivity Gaps and Specialisation Patterns," Working Paper mimeo, University of Groningen.

LUNDVALL, B.-A. (1988): "Innovation as an Interactive Process: From User-Producer Interaction to the National System of Innovation," in *Technical Change and Economic Theory*, ed. by G. Dosi, C. Freeman, R. R. Nelson, G. Silverberg, and L. Soete. Pinter Publisher, London.

——— (1992): *National Systems of Innovation: Toward a Theory of Innovation and Interacting Learning*. Pinter Publisher, London.

MARAVALL, A., AND A. DEL RÍO (2001): "Time Aggregation and the Hodrick-Prescotto Filter," Documento de Trabajo 0108, Banco de España – Servicio de Estudios.

Markusen, J. R., and K. E. Maskus (1999): "Discriminating Among Alternative Theories of the Multinational Enterprise," NBER Working Paper Series 7164, National Bureau of Economic Research, http://www.nber.org/papers/w7164.

Metcalfe, S. J., M. D. Fonseca, and R. Ramlogan (2000): "Innovation, Growth and Competition: Evolving Complexity or Complex Evolution," in *Complexity and Complex Systems in Industry Conference*, University of Warwick.

Moreno-Brid, J. C., and E. Pérez (2003): "Liberalización Comercial y Crecimiento Economico en Centroamérica," *Revista de la CEPAL*, 81, 157–174.

Myrdal, G. (1957): *Economic Theory and Under-developed Regions*. Duckworth, London.

Nelson, R. R. (1988): "Institutions Supporting Technical Change in the United States," in *Technical Changes and Economic Theory*, ed. by G. Dosi, C. Freeman, R. R. Nelson, G. Silverberg, and L. Soete. Pinter, London.

——— (ed.) (1993): *National Innovation Systems: A Comparative Analysis*. Oxford University Press, New York.

——— (1994a): "The Co-evolution of Technology, Industrial Structure, and Supporting Institutions," *Industrial and Corporate Chance*, 3(1), 47–63.

——— (1994b): "What Has Been the Matter with Neo–classical Growth Theory?," in *The Economics of Growth and Technological Change*, ed. by G. Silverberg, and L. Soete, pp. 290–324. Edward Elgar, Aldershot.

——— (1997): "How New is New Growth Theory?," *Challenge*, 40(5), 29–58.

Nelson, R. R., and S. G. Winter (1982): *An Evolutionary Theory of Economic Change*. Harvard University Press, Cambridge, MA.

OECD-IDB (2003): "Business Environment Report: Costa Rica," Caribbean rim investment initiative, Organisation for Economic Co–operation and Development & Inter–American Development Bank.

Parrilli, M. D. (2003): "Le Piccole e Medie Imprese Latinoamericane nell'Era della Globalizzazione: Approcci di Politica per lo Sviluppo Industriale a Confronto," Quaderni del Dipartimento 19/2003, Dipartimento di Economia, Istituzioni, Territorio, Università di Ferrara.

Parto, S. (2004): "Economic Activity and Institutions: Taking Stock," Working Paper mimeo, MERIT.

Pasinetti, L. L. (1981): *Structural Change and Economic Growth. A Theoretical Essay on the Dynamics of the Wealth of Nations*. Cambridge University Press, Cambridge.

Prebish, R. (1950): *The economic Development of Latin America and its Principal Problems*. United Nations, New York.

Quadros, R. (2002): "Global Quality Standards, Chain Governance and the Technological Upgrading of Brazilian Auto-Components Producers," .

Richardson, G. B. (1972): "The Organisation of Industry," *Economic Journal*, 82, 883–896.

Rodríguez-Clare, A. (2001): "Costa Rica's Development Strategy based on Human Capital and Technology: How it got there, the Impact of Intel, and Lessons for other Countries," Written for the human development report of 2001, UNDP, United Nations.

Romer, P. M. (1993): "Idea Gaps and Object Gaps in Economic Development," *Journal of Monetary Economics*, 32(3), 543–573.

Saviotti, P. P., and S. J. Metcalfe (1984): "A Theoretical Approach to the Construction of Technological Output Indicators," *Research Policy*, 13, 141–151.

Silverberg, G. (1987): "Technical Progress, Capital Accumulation and Effective Demand: A Self-Organization model," in *Economic Evolution and Structural Change*, ed. by D. Batten, J. L. Casti, and B. Johansson. Springer-Verlag, Berlin, Heidelberg, New York, Tokio.

Silverberg, G., and B. Verspagen (1995): "Evolutionary Theorizing on Economic Growth," Working Paper WP-95-78, IIASA, Published in The Evolutionary Principles of Economics, edited by K. Dopfer, Norwell, MA: Kluwer Academic Publisher.

Singer, H. (1950): "The Distribution of Gains Between Investing and Borrowing Countries," *American Economic Review*, 40, 473–485.

Solomon, S., and M. Levy (2003): "Pioneers on a New Continent: On Physics and Economics," *Quantitative Finance*, 3(1), c12–c15.

Solomon, S., and E. Shir (2003): "Complexity; A Science at 30," *Europhysics News*, 34(2).

Stanley, M. H. R., L. A. N. Amaral, S. V. Buldyrev, S. Havlin, K. Leschhorn, P. Maass, M. A. Salinger, and E. H. Stanley (1996): "Scaling Behaviour in the Growth of Companies," *Nature*, 379, 804–806.

Thirlwall, A. P. (1979): "The Balance of Payments Constraint as an Explanation of International Growth Rate Differences," *Banca Nazionale del Lavoro Quarterly Review*, XXXII, 45–53.

Valente, M. (2002): "Simulation Methodology: An Example in Modelling Demand," Working paper mimeo, Università dell'Aquila.

Valente, M., and E. S. Andersen (2002): "A Hands-on Approach to Evolutionary Simulation: Nelson and Winter Models in the Laboratory for Simulation Development," *Electronic Journal of Evolutionary Modelling and Economic Dynamics*, 1(1), `http://www.e-jemed.org`.

Verspagen, B. (1993): *Uneven Growth Between Interdependent Economies. The Evolutionary Dynamics of Growth and Technology.* Avebury, Aldershot.

——— (2002): "Evolutionary Macroeconomics: A Synthesis between neo–Schumpeterian and post–Keynesians Lines of Thought," *Electronic Journal of Evolutionary Modelling and Economic Dynamics*, (1007), `http://www.e-jemed.org/1007/index.php`.

YOGUEL, G. (2000): "El Tránsito de la Sustitución de Importaciones a la Economiá Abierta: Los Principales Cambios en la Estructura Industrial Argentina entre los 70's y los 90's," in *El Desempeo Industrial Argentino: Mas allá de la Sustitución de Importaciones*, ed. by B. Kosacoff, G. Yoguel, Bonvechi, and J. Ramos. CEPAL, Santiago del Chile.

A Parameters

Table 2: The benchmark case (Section 5.1)

Parameter[a]	Description	Market/model[b]	S1	S2	S3	S4
H	Constant demand	500	–	–	–	–
D_{t-1}	lagged demand	Init	–	–	–	–
s^D	1 - rate of adjustment to target demand	0.9	–	–	–	–
s^{MS}	1 - rate of adjustment to target market share	0.9	–	–	–	–
α^p	Price 'elasticity'	1	–	–	–	–
α^{y_m}	Quality 'elasticity'	1	–	–	–	–
$isFinal$	Flags sectors in the final market	–	0	0	0	1
λ	Exogenous growth	0	–	–	–	–
σ^2_ϵ	Variance of the demand exogenous growth	0	–	–	–	–
τEx	Number of subsequent inactive periods after which the firm exits	200	–	–	–	–
τE^c	Number of periods between two entries	–	200	100	120	50
τE_{Min}	Minimum number of periods between two entries	–	200	60	60	200
τE_{Max}	Maximum number of periods between two entries	–	350	150	150	500
e^D	Weight given by entering firms to market concentration in forecasting demand	0.5	–	–	–	–
C^F	Fixed costs	1000	–	–	–	–
p_{t-1}	Lagged price	Init[d]	–	–	–	–
mkp	Constant mark-up	0.2	–	–	–	–
ms_{t-1}	Lagged market share	–	0.33	0.1	0.1	0.2
q_{t-1}	Initial quantity (thousands)	Init[d]	–	–	–	–
OB	Initial order (thousand)	Init[d]	–	–	–	–
POB_{t-1}	Initial pre–order (thousand)	Init[d]	–	–	–	–
$Y^{s_F}_{t-1}$	Initial sales in the final market (thousand)	Init[d]	–	–	–	–
sk_{t-1}	Initial stocks	–	1000	200	200	100
$\overline{q}^*_{t-1}$	Initial target demand (thousand)	–	6000	1500	1500	300
a^{q^*}	Quantity change on stock adjustment	0.99	–	–	–	–
b^{q^*}	Quantity change on quantity adjustment	0.99	–	–	–	–
$a^{\overline{q}^*}$	Smooth on target quantity	0.8	–	–	–	–
a^q	Quantity smooth	0.8	–	–	–	–

[a] Into parenthesis the number of lags of the initial value for the lagged variables.

[b] Values that refer to the entire economic system or which are identical across sectors/firms

[c] The parameter is set in the initial period, for the lag of the first event, afterwards it is given by the Max and Min values of the lag.

[d] Initialised by the model in the first period following procedure described in Section 4.1 and then regularly updated.

Parameter[a]	Description	Market/model	S1	S2	S3	S4
μ	Stock ratio	0.2	–	–	–	–
γ	supplier evaluation ratio	0	–	–	–	–
α^{F_p}	Firm price elasticity	1	–	–	–	–
$\alpha_m^{F_y}$	Firm quality elasticity	1	–	–	–	–
$\alpha^{F_{ms}}$	Firm market share elasticity	0	–	–	–	–
η	Differential ratio of external inputs	1	–	–	–	–
η^P	Differential ratio of external inputs (price)	1	–	–	–	–
t_{lbd}	minimum time periods after which LBD takes place	10	–	–	–	–
z^g	rate of growth of competencies through LBD	2e-006	–	–	–	–
z	Maximum increase in competencies by LBD with one single client	0.1	–	–	–	–
$a_{m,i,h}$[b]	Firms' competencies	$rnd \sim U\,[0.4, 0.9]$	–	–	–	–
$\Delta\mu_{a(I)}$	deviation from the competencies average of new entrants	0	–	–	–	–
$\Delta\sigma^2_{a(I)}$	deviation from the competencies variance of new entrants	0	–	–	–	–
β_k	Input quantity coefficient[c]	–	0.5	0.4	0.5	2, 0.6, 2
p_k^I	Input price	Init[d]	–	–	–	–
t_{change}[d]	input monitoring period	$rnd \sim U\,[30, 350]$	–	–	–	–
τ^D_{Max}	Maximum lag between two supplier decisions	350	–	–	–	–
τ^D_{Min}	Minimum lag between two supplier decisions	0	–	–	–	–
$Id_{t=1}Input$	Initial supplier	$rnd \sim U\,[1, n_s]$[e]	–	–	–	–
lp	Ratio of local procurement	1	–	–	–	–
$w_{k,h,t=1}$	Input quality features	1, Init[d]	–	–	–	–

[a]Into parenthesis the number of lags of the initial value for the lagged variables.

[b]Competencies are parameters until learning by doing and/or innovation processes start. After they become variables. Thus, the initialisation refers to initial idiosyncratic capabilities of firms.

[c]Where different values correspond to the different inputs

[d]The parameter is set in the initial period, for the lag of the first event, afterwards it is given by the Max and Min values of the lag.

[e]Where n_s is the number of firms in the supplier sector

Table 3: Experiment I: heterogeneous preferences(Section 5.2)

Parameter	Market/model[a]	S1	S2	S3	S4
α^{y_m}	$rnd \sim U\,[0, 2]$	–	–	–	1.31, 0.76, 1.07, 1.42, 0.38[b]
$\alpha_m^{F_y\,c}$	$rnd \sim U\,[0, 2]$	–	–	–	–

[a]Values that refer to the entire economic system or which are identical across sectors/firms

[b]Each value correspond to one quality feature. The average over the five features is 0.99

[c]Every good has five quality features, both intermediate and final goods. Thus clients and consumers have the same structure of preferences.

Table 4: Experiment II.a: innovation with homogeneous preferences (Section 5.3.1)

Parameter[a]	Description	Market/model[b]	S1	S2	S3	S4
τ^I_{Min}	minimum periods between two consecutive innovations	–	–	–	–	100
τ^I_{Max}	maximum periods between two consecutive innovations	–	–	–	–	250
$\tau^{I\,c}$	periods between two innovations by the same firm	–	–	–	–	$Rnd \sim U\,[150, 250]$
$\tilde{a}^{max}$	maximum variation of competencies through non interactive innovation	–	–	–	–	0.02
$\tilde{a}^{min}$	minimum variation of competencies through non interactive innovation	–	–	–	–	0
ι	1 – the probability of involving the supplier in the innovation	–	–	–	–	0.5
ν	multiplier of the joint production of the new competence	–	–	–	–	0.6

[a]Only parameters with different values from the *benchmark case*, or new parameters are reported.
[b]Values that refer to the entire economic system or which are identical across sectors/firms
[c]The parameter is set in the initial period, for the lag of the first event, afterwards it is given by the Max and Min values of the lag.

Table 5: Experiment II.b: innovation with heterogeneous preferences (Section 5.3.2)

Parameter[a]	Market/model[b]	S1	S2	S3	S4
α^{y_m}	$rnd \sim U\,[0, 2]$	–	–	–	0.48, 0.52, 1, 1.51, 1.81[c]
$\alpha_m^{F_y\,d}$	$rnd \sim U\,[0, 2]$	–	–	–	–

[a]Only parameters with different values from the *benchmark case* or from Table 4 are reported.
[b]Values that refer to the entire economic system or which are identical across sectors/firms
[c]Each value correspond to one quality feature. The average value over the five features is 1.07.
[d]Every good has five quality features, both intermediate and final goods. Thus clients and consumers have the same structure of preferences.

Table 6: Experiment III: high probability of interacting innovation (Section 5.4)

Parameter[a]	Market/model[b]	S1	S2	S3	S4
ι	–	–	–	–	$Rnd \sim U[0, 0.25]$

[a]Only parameters with different values from the *benchmark case* or from Table 4 are reported.
[b]Values that refer to the entire economic system or which are identical across sectors/firms

Table 7: Experiment IV: low local procurement (Section 5.5)

Parameter[a]	Market/model[b]	S1	S2	S3	S4
lp	–	1	1	1	$rnd \sim U[0.02, 0.12]$
β_k	–	0.5	0.4	0.5	2, 0.6, 2, 1[c]
η	–	1	1	1	$rnd \sim U[1.5, 2.5]$
Heterogeneous preferences					
α^{y_m}	$rnd \sim U\,[0, 2]$	–	–	–	0.52, 1.43, 0.52, 1.5, 1[d]
$\alpha_m^{F_y\,e}$	$rnd \sim U\,[0, 2]$	–	–	–	–

[a]Only parameters with different values from the *benchmark case* or from Table 4 are reported.
[b]Values that refer to the entire economic system or which are identical across sectors/firms
[c]Where different values correspond to the different inputs
[d]Each value correspond to one quality feature. The average value over the five features is 1.006.
[e]Every good has five quality features, both intermediate and final goods. Thus clients and consumers have the same structure of preferences.

B Appendix: analytical model description

The model is implemented in Laboratory for Simulation Development - Lsd[49]. Such language implements a simulation step as the updating at the generic time t of all the variables contained in the model. In the following paragraphs we describe with the minimal formalism the main variables used in the model explaining the computation used to update their values at the generic time t.

To simplify the reading we will omit the time index unless it expresses lagged values, in which case we will use the usual notation X_{t-1}. We will also omit, in general, the indexes for the different instances of the variables. For example, each firm in each sector contains many instances of variables for the market share but we will not use indexes for firm, sector and characteristic. The computations make use, in general, of values from other variables and parameters of the model. Listing these elements we will specify the objects in which an element is contained. Unless otherwise specified the reader must understand elements in the same type of objects as being used from the same instance. When this is not the case and index, and its explanation, will be provided.

The paragraph for a variable is composed by the following sections (comments are in small types):

Variable Title — X (`VarX`)

The title of the paragraph reports: extended name of the variable, its symbol used in the text and the label in the model's implementation within parenthesis.

Variable representing behaviour ... of the entity ... computed as a function ...
Text commenting the variable meaning and verbal description of its equation

Containing object: `Son` → `Father`→ `Gran-father`
Object containing the variable and its ancestors

Elements used:
Table listing the elements used in the equation

Element	Description	`In Object`	`LSD`
Y (V)	descr. of Y	`Son`	`VarY`
Z (V-1)	descr. of Z	`Father`	`VarZ`
α (V)	descr. of α	`Grand-father`	`alpha`
Symbol and type: (V)=variable, (V-1)=lagged variable, (P)=parameter	extended name of the element	Obj containing the element	Label used in the code

$$X = f(Y, Z_{t-1}, \alpha)$$

Equation's expression. Note that there are no indexes, meaning that the Y used when computing the generic X must be the instance contained in the same object, while the Z will be contained in the ancestor object.

[49]See `www.business.auc.dk/lsd` for further details on Lsd.

B.1 Production - Quantitative aspects

The quantity produced by firms is determined in three steps. Firstly, it is determined the variation of production in respect of the previous production level, given the expected demand level. Secondly, it is determined the desired production level, under a conservative assumption meant to smooth away volatility in the demand. Thirdly, the actual production level is determined assuming a friction in varying production levels.

Differences between current production and actual demand are compensated by variation of stocks.

B.1.1 Quantity adjustment — q_t^* (`Q_null`)

Desired variation of production in respect of previous period's production. The variation is determined by two goals: producing the same amount of quantity actually sold (both to business and final demand); and producing to keep stocks at the desired level.

Note that the model can also implement "non-linear" production processes, where a sector is both a client and a supplier of another sector. For this reason, the implementation of the model is such that all firms in all sectors make their production decisions in parallel. Consequently, no firm knows with certainty the actual demand it will receive by other firms. Firms use past orders by client firms as an estimate of current business demand.
Containing object: `Firm` → `Market`
Elements used:

Element	Description	`In Object`	`LSD`
POB_{t-1} (V)	Orders placed by clients in the previous period, used as an estimate of the current period orders.	`Firm`	`PreOrderBook`
$Y_{t-1}^{s_F}$ (V)	sales for firms in the final sector	`Firms`	`FinalSales`
sk_{t-1} (V-1)	stock production accumulated up to the previous period	`Market`	`Stock`
a^{q^*} (P)	parameter that smooths the change in quantity according to the changes in stock	`Firm`	`a_qnull`
b^{q^*} (P)	parameter that smooths the change in quantity according to the changes on previous quantity	`Firm`	`b_qnull`
μ (P)	parameter indicating the ratio of needed quantity to be produced to cumulate the required stock	`Firm`	`mu`

$$q_t^* = a^{q^*}\left[\left(POB_{t-1} + Y_t^{s_F}\right)(1+\mu) - sk_{t-1}\right] + b^{q^*}\left[POB_{t-1} + Y_t^{s_F} - q_{t-1}\right] \qquad (1)$$

B.1.2 Target quantity — $\overline{q}_t^*$ (`Q_target`)

Desired level of production, computed as a smoothed value between the previous period desired production and the new desired variation.
Containing object: `Firm` → `Market`
Elements used:

Element	Description	In Object	LSD
$a^{\overline{q}_t^*}$ (P)	parameter indicating how much the target quantity follows the quantity changes (q_*)	Firm	a_qt
q_t^* (V)	quantity variation decision	Firm	Q_null
$\overline{OB}_{\mid t}$ (V)	moving average of the orders received by the firm through time	Firm	AvOB
$\overline{q}_{\mid t}$ (V)	moving average of the quantity produced by the firm through time	Firm	AvQ
$isFinal$ (P)	Parameter indicating whether the sector serve final demand or not	Market	IsFinal

$$\overline{q}^* = \begin{cases} \overline{OB}_{\mid t} + a^{\overline{q}^*} \cdot q_t^* & \text{, if } isFinal = 0 \\ \overline{q}_{\mid t} + a^{\overline{q}^*} \cdot q_t^* & \text{, if } isFinal = 1 \end{cases} \tag{2}$$

B.1.3 Quantity — q_t (Quantity)

Actual quantity produced, computed as a smoothed variation between the previous period's production and the new target production. Unless when the firm sells only in the intermediate market, and all the clients change supplier, leaving it without demand. In this latter case the production is rapidly dropped.
Containing object: Firm → Market
Elements used:

Element	Description	In Object	LSD
a^q (P)	parameter indicating how much the actual quantity varies on its own past history and how much on the target quantity (smooth adjustment to target quantity)	Firm	a_q
$\overline{q}_t^*$ (V)	target quantity	Firm	Q_target
$isFinal$ (P)	Parameter indicating whether the sector serve final demand or not	Market	IsFinal
POB_{t-1} (V)	Orders placed by clients in the previous period, used as an estimate of the current period orders.	Firm	PreOrderBook

$$q_t = \begin{cases} a^q \cdot q_{t-1} + (1 - a^q) \cdot \overline{q}_t^* & \text{, if } isFinal = 1 \\ & \text{if } isFinal = 0 \;\&\; POB_{t-1} \neq 0 \\ (a^q - 1) \cdot \cdot q_{t-1} & \text{, if } isFinal = 0 \;\&\; POB_{t-1} = 0 \end{cases} \tag{3}$$

B.1.4 Stocks — sk (Stock)

Stock level, computed as the previous period's stock, plus production and minus sales.
Containing object: Firm → Market
Elements used:

Element	Description	In Object	LSD
sk_{t-1} (V-1)	stocks from the previous period	Firm	Stock
q_t (V)	quantity produced	Firm	Quantity
Y_t (V)	quantity sold	Firm	Sales

$$sk = sk_{t-1} + q_t - Y_t \tag{4}$$

B.2 Demand

There are two types of demand for a firm: firm's final demand and business demand. Total final demand is determined at sector level as a function of the prices and qualities of all products in the market. Firms' individual amount of final demand is derived as their market share times the total final demand. Business demand is the amount of products requested by firms in other sectors. Business demand is determined by orders delivered by client firms to their suppliers. Total business demand is derived by summing up individual firms' business demand.

B.2.1 Total Sales — Y (`Sales`)

The total sales of a firm is the sum of its individual business demand and final demand.
Containing object: `Firm` → `Market`
Elements used:

Element	Description	In Object	LSD
OB (V)	Order book, i.e. the quantity requested by client firms	`Firm`	`OrderBook`
Y^{S_F} (V)	sales in the final market	`Firm`	`FinalSales`

$$Y = OB + Y^{S_F} \tag{5}$$

B.2.2 Business Demand — OB (`OrderBook` and `PreOrderBook` = `OrderBook`$_{t-1}$)

Business demand for a firm. This variable is computed after every firm in every sector updated its production variable. Given the technical coefficients firms then send purchasing orders to their suppliers in the up-stream sectors. The order book of a firm sums up all the orders received by client firms, i.e. firms to which the firm is a supplier.

The model implements firms producing one single product, so that there is no need to specify the sector if one indicates a specific firm. Obviously, firms selling only in final markets have this variable constantly equal to zero.

Note that his variable is used for two different purposes. Firstly, its lagged value is used as a proxy to estimate the current business demand, and determine the production decision of the firm. Secondly, its current value, as the actual business demand, determines the level of sales.
Containing object: `Firm` → `Market`
Elements used:

Element	Description	In Object	LSD
qI_i^j (V)	Amount of input requested by firm j supplied by firm i.	`Input`	`Tot`
$Client\{i\}$	Set of firms buying products from firm i	`---`	`---`

$$OB_i = \sum_{j \in Client\{i\}} qI_i^j \tag{6}$$

B.2.3 Inputs quantity — qI (Tot)

Quantity of input needed for each output unit, given by a technical coefficient
Containing object: `Input`→ `Firm` → `Market` Elements used:

Element	Description	In Object	LSD
q (V)	quantity of output produced by the firm	Firm	Quantity
β_k (P)	technical coefficient of input k	Input	quantity_coeff
lp (P)	local procurement: percentage of acquisition of inputs from local suppliers of input k	Input	lp

$$qI_k = \beta_k \cdot lp \cdot q \tag{7}$$

B.2.4 Final sales — Y^{S_F} (FinalSales)

Firm's sales to final demand. Computed as the market share for the final demand of each firm, times total final demand for the market. The market share used here is a 'nominal' market share that accounts for the relative competitiveness of the firm in terms of quality and prices. In the case in which the firm sells only on the final market, it coincides with the real market share ms (a part from the adjusting effect)
Containing object: `Firm` → `Market`
Elements used:

Element	Description	In Object	LSD
msV_f (V)	firm's 'nominal' market share in the final market (firm's relative competitiveness)	Firm	MsV
D (V)	total demand in the final market	Market	Demand

$$Y^{S_F} = msV_f \cdot D \tag{8}$$

B.2.5 Final Demand — D (Demand)

Total final demand for the market (i.e. excluding business demand). It is computed as a smoothed adjustment between its own previous value and the current level of the target final demand. Markets not selling to final consumers have no final demand.
Containing object: `Market`
Elements used:

Element	Description	In Object	LSD
$isFinal$ (P)	Parameter indicating whether the sector serve final (= 1) demand or not (= 0)	Market	IsFinal
D^* (V)	Target final demand for the sector	Market	TargetDemand
D_{t-1} (V-1)	Lagged final demand	Market	Demand
s^D (P)	smoothing parameter for the demand	Market	smoothDemand

$$D = \begin{cases} s^D D_{t-1} + \left(1 - s^D\right) D^*_t & \text{, if } isFinal = 1 \\ 0 & \text{, if } isFinal = 0 \end{cases} \tag{9}$$

B.2.6 Target demand — D^* (TargetDemand)

Target level of final demand. It is determined as a function of the average quality level for each of the characteristics defining the product. The (inverse of) price is used as an added characteristic. An exogenous process of growth is added.
Containing object: `Market`
Elements used:

Element	Description	In Object	LSD
H (P)	constant	`Market`	`Constant`
$\overline{p}_{t-1}$ (V-1)	Average lagged price of the final sector	`Market`	`AvPrice`
$\overline{y}_m$ (V)	Average values of the quality m features	`Characteristic`	`AvValue`
α^p (P)	Parameter of sensitivity to price	`Market`	`alphaPrice`
α^y_m (P)	Parameter of sensitivity to quality features (one for each m feature of the good)	`Characteristic`	`alpha`
λ (P)	Parameter of exogenous growth of the demand	`Market`	`lambda`
ϵ (P)	Variation in the demand growth	`Market`	`- - -`
σ^2_ϵ (P)	Variance of the growth process	`Market`	`SigmaD`

$$D^* = H \cdot \exp^{\lambda t+\epsilon} \cdot \left(1/\overline{p}_{t-1}\right)^{\alpha^p} \prod_{m=1}^{M} \overline{y}_m^{\alpha^y_m}, \quad \epsilon \sim \left(0, \sigma^2_\epsilon\right) \tag{10}$$

B.2.7 Nominal market share for final demand — msV_f (MsV)

Nominal market share of a firm on the market for the final demand, when present. Computed as a smoothed adjustment of previous period value toward the target market share. The difference with the real market share is that this one is computed before selling to the market, and measures the market share that the firm would have on that market. This is different when the firm also sells to an intermediate sector. In this second case the market share is the real pone computed as the ratio of sales.
Containing object: `Firm` → `Market`
Elements used:

Element	Description	In Object	LSD
ms^* (V)	Target market share for final demand	`Firm`	`TargetMs`
$msV_{f,t-1}$ (V-1)	Lagged market share for final demand	`Firms`	`MsV`
s^{MS} (P)	Smoothing parameter for the market share	`Market`	`smoothMs`

$$msV_f = s^{MS} msV_{t-1} + \left(1 - s^{MS}\right) ms^*_t \tag{11}$$

B.2.8 Real market share — ms (Ms)

The real market share of a firm in all markets, in a given time of period. Its is computed as the actual ratio of total selling of the firm, which account for both intermediate sales and final ones.
Containing object: `Firm` → `Market`

Elements used:

Element	Description	In Object	LSD
$\sum_s Y$ (V)	Total sales of the sector s	Market	TotalSales
Y (V-1)	Total sales of the single firm	Firm	Sales
ms_{t-1} (P)	market share in the previous period	Firm	Ms

$$ms = \begin{cases} \frac{Y}{\sum_s Y} & \text{, if } \sum_s Y > 0 \\ ms_{t-1} & \text{, if } \sum_s Y = 0 \end{cases} \tag{12}$$

B.2.9 Target market share for final demand— ms^* (TargetMs)

Theoretical share of the final demand of the firm, to which actual shares slowly adjust. It is computed as the ratio between the quality index of the firm and the sum of all quality indexes of the firms in the market.
Containing object: Firm → Market Elements used:

Element	Description	In Object	LSD
I (V)	firms' competitiveness index	Firm	IndexQ
n_S (P)	Number of firms in the market	Market	(count)

$$ms^* = \frac{I}{\sum_{i=1}^{n_S} I_i} \tag{13}$$

B.2.10 Competitiveness index — I (IndexQ)

Quality index meant to represent the competitiveness of the firm in the final market, or better the product competitiveness (Silverberg, 1987) It is computed as the product of all quality levels of the firm's product, measured over the characteristics. The inverse of price acts as a further characteristic.
Containing object: Firm → Market
Elements used:

Element	Description	In Object	LSD
p_{t-1} (V)	price of firm output in the previous period	Firm	Price
y_m (V)	output features	OutCh	y
α^p (P)	parameter of sensitivity to price	Market	alphaPrice
α^y_m (P)	parameter of sensitivity to quality features (one for each m feature of the good)	Characteristic	alpha
M (P)	Number of characteristics defining the product in the sector	Market	- - -

$$I = (1/p_{t-1})^{\alpha^p} \prod_{m=1}^{M} y_m^{\alpha^y_m} \tag{14}$$

B.2.11 Average output price — $\overline{p}$ (AvPrice)

Average price for the final demand. The price is computed averaging single firms' prices weighted with their market shares of final demand.
Containing object: `Market`
Elements used:

Element	Description	In Object	LSD
p_i (V)	Price of the output of firm i	`Firm`	`Price`
$ms^i_{f,t-1}$ (V-1)	Previous period's market share of the final demand market for firm i.	`Firm`	`Ms_final`
n_S (P)	Number of firms in the market S	`Market`	`---`

$$\overline{p} = \sum_{i=1}^{n_S} p_i \cdot ms^i_{f,t-1} \tag{15}$$

B.2.12 Average quality — $\overline{q}_m$ (AvValue)

Average quality for each characteristic of products sold in a sector. Computed as the average of all products sold by firms weighted with the market shares on the final market.
Containing object: `Characteristic` → `Market`
Elements used:

Element	Description	In Object	LSD
y^i_m (V)	quality of the feature m of the output produced by firm i	`OutCh`	`y`
$ms^i_{f,t-1}$ (V-1)	market share for final demand of firm i	`Firm`	`Quantity`
n_S (P)	Number of firms in the market S	`Market`	(count)

$$\overline{q}_m = \sum_{i=1}^{n_S} y^i_m \cdot ms^i_{f,t-1} \tag{16}$$

B.3 Production - Qualitative aspects

The quality of products sold in a market is defined over an exogenous number of product's characteristics. The level of quality of the product for a firm in respect of each characteristic is determined by two factors: quality of the inputs and competences of the firm. Competences represent the capacity of transforming each characteristic of each input in quality levels of the product.

The price of products is treated in the model as an added characteristic, but for the fact that it is determined in a different manner: price is computed as a mark-up over the costs of inputs.

The model can represent either "exogenous" inputs, obtained from sectors not represented in the model, and "endogenous" inputs, from sectors represented in the model. This second types of inputs are chosen by client firms every given number of periods, using a random choosing function with probabilities proportional to the average quality of the products in the input sector.

B.3.1 Quality — y_m (y)

Quality levels of the characteristic a firm's product. The number of characteristics must be identical for firms in each sector, while it can vary for firms in different sectors. Computed as the average of competencies times qualities of inputs.
Containing object: `OutCh` → `Output` → `Firm` → `Market`
Elements used:

Element	Description	In Object	LSD
$a_{m,i,h}$ (P)	Firm's competencies in producing quality level m using characteristic h of input i	`CompInCh`	`a`
$w_{i,h}$ (P)	Quality level of characteristic h for input i	`InCh`	`w`
$NInCh_i$ (P)	Number of characteristics of input i	`InCh`	(count)
NIn_S (P)	Number inputs used in the production of the output in sector S	`Input`	(count)

$$y_m = 1 + \frac{\sum_{i=1}^{NIn_S} \sum_{h=1}^{NInCh_i} a_{m,i,h} \cdot w_{i,h}}{\sum_{k=1}^{NIn_S} NInCh_k} \tag{17}$$

B.3.2 Supplier evaluation— EV (Evaluate)

Each firm, when it has to decide whether to change the supplier, it first evaluate the firms in the supplier market. The evaluation is one of the conditions of the supplier change, as the buyer firm decide to look for a new supplier only if the current one is below average. The evaluation is done in a way which is similar to the consumers' demand. In this case, each buyer is allowed to have its own preferences with respect to the different features of the input (included price). Moreover, a bandwagon effect is introduced, through the observation of the suppliers market share.

Note that the evaluation is done differently for each input used and bought from local suppliers, as they refer to different sectors/markets.
Contained in object `Firm` → `Market`
Elements used:

Element	Description	In Object	LSD
p_{t-1} (V)	price of supplier's output in the previous period	`Firm`	`Price`
y_m (V)	supplier's output features	`OutCh`	`y`
α^{Fp} (P)	firm parameter of sensitivity to price	`Firm`	`alphaPriceF`
α^{Fy}_m (P)	firm parameter of sensitivity to quality features (one for each m feature of the good)	`InCh`	`alphaF`
M (P)	Number of characteristics defining the product in the sector	`Market`	`---`
α^{Fms} (P)	firm parameter of sensitivity to supplier visibility (market share)	`Firm`	`alphaMsF`
ms_{t-1} (V)	supplier's market share in the previous period	`Firm`	`Ms`

$$EV_i = (1/p_{j,t-1})^{\alpha_i^{Fp}} \cdot \prod_{m=1}^{M} y_{j,m}^{\alpha_{i,m}^{Fy}} \cdot (ms_{j,t-1})^{\alpha_i^{Fms}} \quad (18)$$

$\forall j \neq i$, where i is the client and j are the suppliers.

B.3.3 Supplier selection — Id_i^{Input} (IdSupplier)

Identification number of the supplier of the input. A firm consider whether to change supplier only every several time steps. When it does, it monitor the various suppliers in the market through the evaluation procedure (B.3.2). Nonetheless, it first consider whether it wants to change, by observing the changes in the market share, and the average attractiveness of the suppliers' good. If this is the case, it considers the one with the best evaluation, and compare it with the actual one. It shift supplier only when considering the gain higher than the risk and transaction costs it may incur. Once the supplier has been changed, the procedure updates the input price and qualities.

Note that, besides changing the Id^{Input}, the client firm updates also all the parameters of the quality levels of the input, and the price, of its input. Moreover, the LBD is interrupted and reset to 0, as the buyer starts a new learning process.

Contained in object `Input` → `Firm` → `Market`

Elements used:

Element	Description	`In Object`	`LSD`
n_S (P)	number of firms in the input sector S	—	—
EV_i (V)	valuation index of supplier i	`Supplier`	`Evaluate`
$\overline{EV}$ (V)	average evaluation index for all the supplying market	`- - -`	`- - -`
Id_S^{Firm} (P)	identification number of firms in the input sector S.	`Firm` (in the input sector S)	`IdFirm`
t_{change} (P)	Value extracted from a uniform distribution on discrete values indicating time of reviewing suppliers. At $t = 1$ and every time the firm monitor the market, t_{change} is extracted from the uniform $\left(t + t^{min}, t + t^{max}\right)$	`Input`	`CounterDecision`
$\overline{ms}_{\mid t}$ (V)	moving average of the evaluating firm market share	`Firm`	`AvMs`
ms^* (V)	target market share of the evaluating firm	`Firm`	`TargetMs`
γ (P)	proxy for risk aversion and transaction costs in shifting supplier	`Firm`	`gamma`
η (P)	ratio by which the external input is different from the average of the local ones	`Firm`	`eta`
η^P (P)	ratio by which the external input price is different from the average of the local ones	`Firm`	`etaP`
w_h (V)	value of each input feature	`InCh`	`w`
$\overline{w}$ (V)	average of all input features in the firm's sector	`Input`	`Avw`
$\overline{p}^I$ (V)	average of all input prices in the firm's sector	`- - -`	`- - -`

$$Id_i^{Input} = \begin{cases} rnd \sim U\left[1, n_S\right] & \text{, if } t = 0 \\ Id_{t-1,i}^{Firm} & \text{, if } t \neq t_{change} \\ Id_{t-1,i}^{Firm} & \text{if , } t = t_{change} \text{ AND } EV_i \geq \overline{EV} \\ & \text{AND } (\overline{ms}_{|t} \geq \overline{ms}_{|t,t-1} \text{ OR } ms^* \geq \overline{ms}_{|t,t-1}) \\ Id_j^{Firm} : EV_j = \max\left\{EV\right\} & \text{, if } t = t_{change} \text{ AND } EV < \overline{EV} \\ & \text{AND } (\overline{ms}_{|t} < \overline{ms}_{|t,t-1} \text{ OR } ms^* < \overline{ms}_{|t,t-1}) \\ & \text{AND } EV_j > EV_{i,t-1}\left(1+\gamma\right) \end{cases} \quad (19)$$

For computational simplicity if a client firm chooses (or maintains) a supplier that exits the market in the following period, the buyer is forced to choose a supplier that has a positive market share.

The inputs that are not acquired from local suppliers are updated with the same timing of the supplier change, and with a value which is a deviation from the average inputs qualities. The deviation allows for external market that provide better or worst inputs. We provide the equation only for the update of those inputs, as the others assume the values of the output features of the supplier.

$$w_h = \eta \overline{w} \quad (20)$$

$$p_k^I = \eta^P \overline{p}^I \quad (21)$$

B.4 Industrial Dynamics

We represent a form of industrial dynamics in term of entry and exit of firms in each sector, The two processes are independent: firms exit when they do not realise sales for a given number of sequential periods. When firms in intermediate markets are about to exit, their suppliers are forced to change. Entry occurs at a random rate, similar in all markets. Below we report the way in which entering firm are initialised.

B.4.1 Firms exit — *Exit* (Exit)

When the conditions are met the object containing the exiting firm is cancelled. Concomitantly, all clients of the exiting firm will have to choose a new supplier.
Containing object: `Market`
Elements used:

Element	Description	In Object	LSD
τ^{Ex} (P)	number of sequential periods after which an inactive firm is cancelled	`Market`	`ThExit`
Y_t (V)	quantity sold	`Firm`	`Sales`
Y_t^0 (V)	number of sequential periods in which the firms has not sold goods	`Firm`	`Inactive`

$$Exit = \begin{cases} 1 & \text{, if } Y_t^0 > \tau^{Ex} \\ 0 & \text{, if } Y_t^0 \leq \tau^{Ex} \end{cases} \quad (22)$$

where $Y_t^0 = Y_{t-1}^0 + 1$ if $Y_t = 0$.

B.4.2 Firms entry — *Entry* (Entry)

Entry occurs at a random rate and the equation initialises a firm as a new one with its own random idiosyncratic features, on average similar to the ones of the existing firms in the same market. We use various parameters to play on the features of the entering firms, in terms of competencies, expected demand, etc. Here we indicated the elements that are initialised differently from the first period of the simulations. The remaining elements are equal to other firms when this is the case by construction, or they are recomputed according to the features of the firm (for example once the expected demand is worked out, the quantities, order book, stocks, etc, are all computed as explained in the rest of the appendix).
Containing object: `Market`
Elements used:

Element	Description	In Object	LSD
τ^E_{Min} (P)	Minimum number of periods between one entry and the following one	`Market`	`MinEntry`
τ^E_{Max} (P)	Maximum number of periods between one entry and the following one	`Market`	`MaxEntry`
τ^E (V)	number of periods between two firms entry	`Market`	`CounterEntry`
Id_i^{Input} (V)	identification number f the input supplier	`Input`	`IdSupplier`
n_S (P)	number of firms in the input sector S	—	—
Id_S^{Firm} (P)	identification number of firms in the input sector S.	`Firm` (in the input sector S)	`IdFirm`
τ^{Ex} (P)	number of sequential periods after which an inactive firm is cancelled	`Market`	`ThExit`
Y_t^0 (V)	number of sequential periods in which the firms has not sold goods	`Firm`	`Inactive`
$ms_{S,i}$ (V)	market share of firm i in input sector S	`Firm` (in the input sector S)	`Ms`
$\overline{p}$ (V)	average price in the market in the sector in which the firm enters	`Market`	`AvPrice`
p (V)	price of the entering firm in the first period	`Firm`	`Price`
$a_{m,i,h}$ (P)	Firm's competencies in producing quality level m using characteristic h of input i	`CompInCh`	`a`
$\mu_{a(I)}$ (V)	average level of cross firms competencies in the given competence category m, for the given input i and for the specific feature of the input h	`Market`	`CompAv`
$\sigma^2_{a(I)}$ (V)	variance of cross firms competencies levels in the given competence category m, for the given input i and for the specific feature of the input h	`Market`	`CompVar`

$\Delta\mu_{a(I)}$ (P)	deviation from the competencies average	—	—
$\Delta\sigma^2_{a(I)}$ (P)	deviation from the competencies variance	—	—
$E(POB)$ (V)	expected demand from clients	—	—
$E\left(Y^{S_f}\right)$ (V)	expected final demand	—	—
e^D (P)	parameter indicating how much importance is given to the market concentration when deciding the initial quantity to produce	`Market`	`Edemand`
Hf (V)	Herfinal Index for the market concentration	`Market`	`Herf`
$OB_{t-1,i}$ (V)	Input orders to each firms i in the same sector in the period preceding the entrance	`Firm`	`OrderBook`
D_{t-1} (V)	final demand in the period preceding firm entrance$i$ in the same sector in the period preceding the entrance	`Firm`	`Demand`
$isFinal$ (P)	parameter indicating whether the sector serve final (= 1) demand or not (= 0)	`Market`	`IsFinal`

Entry rate : A new firm in each sector enters a number of periods $\tau^E = U\left(\tau^E_{Min};\tau^E_{Max}\right)$ after the previous entry.

Inputs : first, the input suppliers are initialised: for each input a random supplier is allocated[50] and the firm is allowed to change it after a short number of periods (30). Accordingly, input features are updated in the entering firm.

$$Prob\left(Id_i^{Input} = Id_{S,i}^{Firm}\right)\begin{cases} = 1/n_S & \text{, if } Y_t^0 < \tau^{Ex} - 1 \\ \propto ms_{S,i} & \text{, if } Y_t^0 \geq \tau^{Ex} - 1 \end{cases} \tag{23}$$

Price : the initial price is set as the average price in the market, but is changed in the following period, depending on firms own features (as in B.6.1)

$p = \overline{p}$

Competencies : for each firm's competencies in producing good's feature m using characteristic h of input i the sectoral mean and variance are computed. Both values can be changed to allow average higher (lower) competencies, or higher (lower) randomness and variance in the new distribution

$a_{m,i,h} = RND \sim N\left(\mu_{a(I)} + \Delta\mu_{a(I)},\ \sigma^2_{a(I)} + \Delta\sigma^2_{a(I)}\right)$

Quantity : the entrant firm starts to produce a 'guessed' amount of quantity and stocks although it still does not have a client, given an expected demand. The expectation is formed observing the previous period demand (final or business), the number of competitors in the market, and the concentration of the market — which proxies for the probability that a client will shift to the new entrant. For the computation of the actual quantity produced (B.1.3) the quantity in the previous period q_{t-1} is set to 0.

$$E(POB) = e^D \cdot \left(\frac{\sum_i OB_{t-1,i}}{n}\right)^{(1-Hf)} + \left(1 - e^D\right) \cdot \frac{\sum_i OB_{t-1,i}}{n} \tag{24}$$

[50]For computational reasons it might happen that the drawn supplier is actually exiting the market. When this is the case the new firm is allowed to change its own supplier as shown in B.3.3

$$E\left(Y^{S_f}\right) = e^D \cdot (D_{t-1}/n)^{(1-Hf)} + \left(1-e^D\right) \cdot D_{t-1}/n \tag{25}$$

The target quantity is set at the level of the demand if the market was equally shared among firms:

$$\overline{q}^* = \begin{cases} \frac{\sum_i OB_{t-1,i}}{n} & \text{, if } isFinal = 0 \\ D_{t-1}/n & \text{, if } isFinal = 1 \end{cases} \tag{26}$$

All remaining variables are set to 0 and computed in the following round. The remaining parameters that have not been mentioned and that change across firms, are set as for initial firms.

B.5 Competence increase (innovation)

This version of the model represents two way in which the competencies are increased. The first one assumes that increase in the production and investment in inputs increase the capabilities to produce the final good, which can be thought both as a vintage effect and a various types of learning (by using, interacting, producing, etc.)

The second one is a process of innovation that occurs randomly only in the sectors that sell to the final market. Parts of the innovations occur as an outcome of the interaction between user and supplier, while the remaining affect only the final sector's firm.

B.5.1 Competencies variation (learning) — $\hat{a}$ (`Lbd`)

Each firm, while undergoing production and investment, increase its capabilities in transforming inputs into output. The learning process increases each competencies of the firm building on the existing distribution of competencies. Thus, competencies increase as a function of their starting value, relatively to the the other competencies. The same share is maintained through time, until an innovation occurs. Competencies variation is not infinite, but limited to a small increase, and learning restarts each time the firm changes the supplier, under the assumption that a new process of learning is needed to deal with the new type of input.
Containing object: `Firm` → `Market`
Elements used:

Element	Description	`In Object`	`LSD`
t_{lbd} (P)	minimum period after which LBD starts (mainly used to avoid influence of the initial oscillation on learning)	`Firm`	`lbt`
z (P)	maximum increase of competencies with one supplier (max LBD)	`Firm`	`z`
z^g (P)	rate of growth of learning	`Firm`	`zg`
q (V)	quantity produced by each firm, used to obtain the unit variable cost	`Firm`	`Quantity`
$NInCh_i$ (P)	Number of characteristics of input i	`InCh`	(count)
NIn_S (P)	Number inputs used in the production of the output in sector S	`Input`	(count)
$NOutCh$ (P)	Number of characteristics of the output	`OutCh`	(count)

$$\hat{a}_{m,i,h} = z \cdot \left[1 - \exp \left(-z^g \cdot \sum_t q_t \cdot \frac{a_{m,i,h}}{\sum_{m=1}^{NOutCh} \sum_{i=1}^{NIn_S} \sum_{h=1}^{NInCh_i} a_{m,i,h}} \right) \right] \tag{27}$$

B.5.2 Competence upgrading (innovation) — $\tilde{a}$ (`Innov`)

Only firms in the final sectors perform direct innovation different from the embodied innovation represented in the input–output framework and from the learning/vintage effect represented in the learning equation. Innovation is only partly endogenous. In fact, timing is exogenous. If the firms innovates individually, the outcome is exogenously determined, randomly. If the innovation occurs through an interactive process, i.e. with the supplier, the outcome is determined by the initial competencies of the two firms. Each time a firm innovates, it increases the value of one single competence, which is selected according to consumers preferences.

Once the upgrading has taken place, the competencies share are changed, and so does the competence variations through learning (the firm is specialising in a new asset)

Containing object: `Firm` → `Market`

Elements used:

Element	Description	In Object	LSD
$isFinal$ (P)	parameter indicating whether the sector serve final (= 1) demand or not (= 0)	`Market`	`IsFinal`
τ^I_{Min} (P)	Minimum number of periods between two consecutive innovations	`Firm`	`MinInnov`
τ^I_{Max} (P)	Maximum number of periods between two consecutive innovations	`Firm`	`MaxInnov`
τ^I (V)	number of periods between two innovations by the same firm	`Firm`	`CounterInnov`
$\tilde{a}^{max}$ (P)	maximum variation of competencies through innovation by a single firm	`Firm`	`Maxa`
$\tilde{a}^{min}$ (P)	minimum variation of competencies through innovation by a single firm	`Firm`	`Mina`
ι (P)	one minus the probability of involving the supplier in the innovation	`Firm`	`ProbInnSup`
ν (P)	multiplier of the joint production of the new competence	`Firm`	`nu`
α^y_m (P)	Parameter of sensitivity to quality features (one for each m feature of the good)	`Characteristic`	`alpha`
a^σ (V)	Competence of the supplier	`CompInCh`	`a`
a^χ (V)	Competence of the client	`CompInCh`	`a`

The probability that an innovator chooses to involve the supplier:

$$\Pr\left(Interact = 1\right) = 1 - \iota$$

The increase in the selected competence a^χ, used to produce the quality feature $m^\chi \propto \alpha^y_m$ of the output, with the input i^χ, and its randomly selected feature h^χ by firm l in the final sector s^F is then:

$\forall i^{\chi}$, if $isFinal = 1$ AND $\tau^I = 0$

$$\tilde{a}^{\chi}_{m,i,h} = \begin{cases} = \tilde{a}^{\sigma}_{m,i,h} = 0.2 \cdot \left[1 - \exp\left(\nu \cdot a^{\sigma}_{m,i,h,k,s \neq s^F} \cdot a^{\chi}_{m,i,h,l,s^F}\right)\right] & \text{, if } Interact = 1 \\ rnd \sim U\left[\tilde{a}^{min}, \tilde{a}^{max}\right] & \text{, if } Interact = 0 \end{cases} \tag{28}$$

where the indexes of the supplier firm's competence are defined as follows: k^{σ} is the supplier of input i^{χ}, s the input market, $m^{\sigma} = m^{\chi}$, the input i^{σ} to which apply the competence and its characteristic $h^{\sigma} = h^{\chi}$ are randomly selected within the category m^{σ}.

B.6 Financial accounts

The model records the financial statuses of firms during their life times. The most important variable is the price of products, determined by firms using a mark-up on the variable costs. Firms record the following financial variables: revenues, profits, financial capital (i.e. cumulated net profits). Further extension of the model may exploit the financial data to implement, for example, investment capacities or a financial sector, currently not implemented.

B.6.1 Output price — p (`Price`)

Price of the final good as a mark-up decision of the single firm.
Containing object: `Firm` → `Market`
Elements used:

Element	Description	In Object	LSD
mkp (P)	mark-up applied to total variable costs. (initially given, has to be endogenised in the firm decision as a function of input price, quality feature and market share change)	`Firm`	`mark-up`
c^V (V)	variable costs	`Firm`	`VariableCosts`
q (V)	quantity produced by each firm, used to obtain the unit variable cost	`Firm`	`Quantity`

$$p = \begin{cases} \dfrac{c^V}{q}(1 + mkp) & \text{if } q > 0 \\ \displaystyle\sum_{k=1}^{K} p^I_k \cdot \beta_k & \text{if } q = 0 \end{cases} \tag{29}$$

B.6.2 Variable costs — c^V (`VariableCosts`)

Variable costs, computed as the costs of inputs used for the production.
Contained in object `Firm` → `Market`
Elements used:

Element	Description	In Object	LSD
q (V)	quantity of output produced by the firm	Firm	Quantity
β_k (P)	technical coefficient of input k	Input	quantity_coeff
p^I_k (V)	price of each input k, initially given (when the input is bought on a general input market; else, given by the output price of the supplier firm)	Input	price_input

$$c^V = \sum_{k=1}^{K} \beta_k \cdot q \cdot p^I_k \tag{30}$$

B.6.3 Revenues — R (Revenues)

Total revenues from sales, computed as the price times sales.
Containing object: Firm → Market
Elements used:

Element	Description	In Object	LSD
Y (V)	quantity sold by the firm (different from the quantity produced, depending on sectors)	Firm	Sales
p (V)	price of output	Firm	Price

$$R = Y \cdot p \tag{31}$$

B.6.4 Profits — π (Profit)

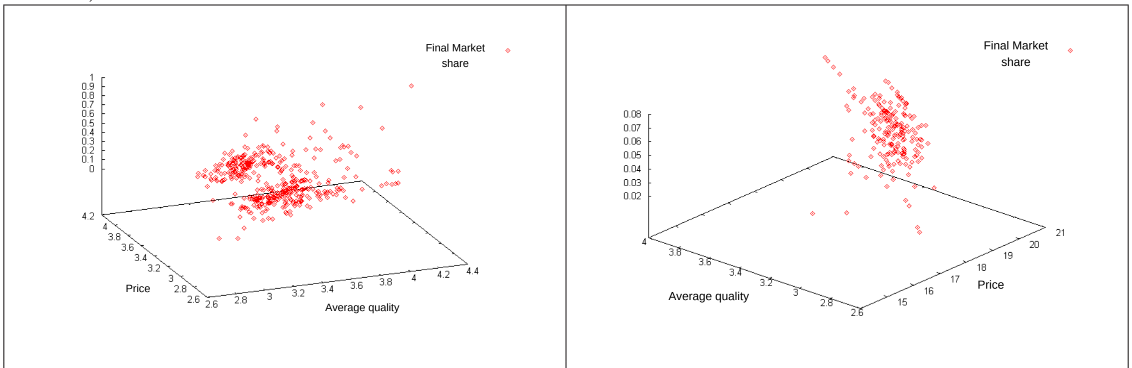
Profits (or losses), computed as the revenues minus variable costs and fixed costs, supposed exogenous.
Containing object: Firm → Market
Elements used:

Element	Description	In Object	LSD
R (V)	firm revenues	Firm	Revenues
c^V (V)	variable costs	Firm	VariableCosts
c^F (P)	fixed costs, initially given	Firm	FixedCosts

$$\pi = R - c^V - c^F \tag{32}$$

C Figures Appendix

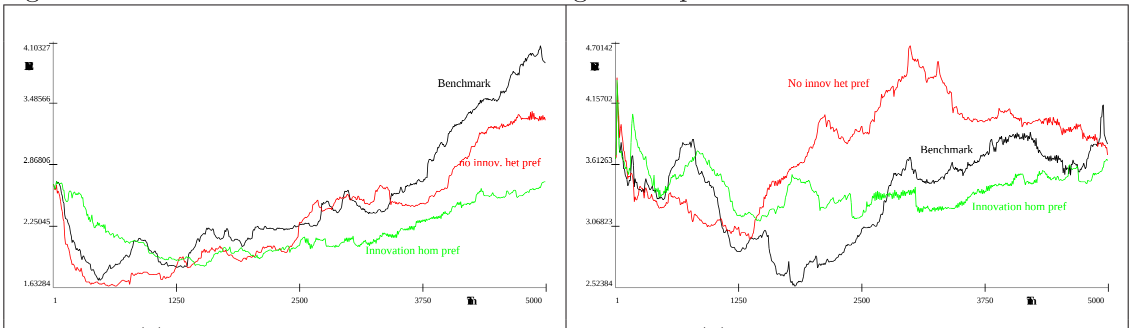
Figure 24: Heterogeneous preferences: quality and price features on market shares (observations)



(a): Intermediary sectors (b): Final sector

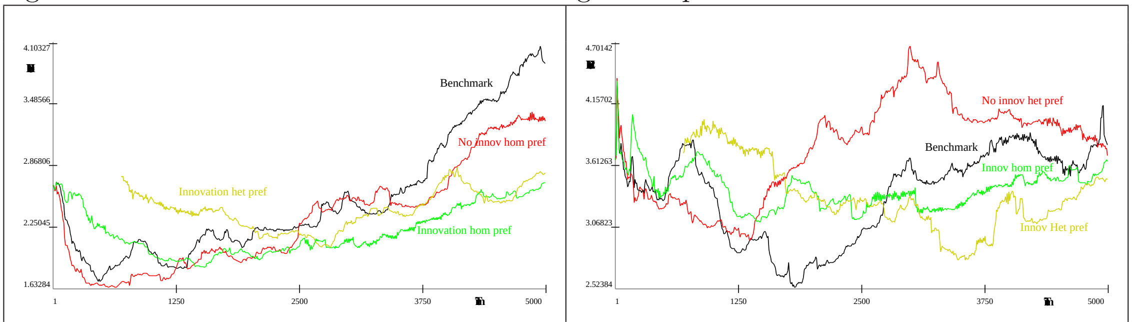
The figure shows the result of a cross simulation comparison where the firms' market share (vertical axis) in the final period ($t = 5000$) is related to the average quality and the price of their output. Results for intermediary sectors in box (a) and final sectors in box (b).

Figure 25: The effect of innovation with homogeneous preferences on market concentration



(a): IHI compared: sector 1 (b): IHI compared: sector 2

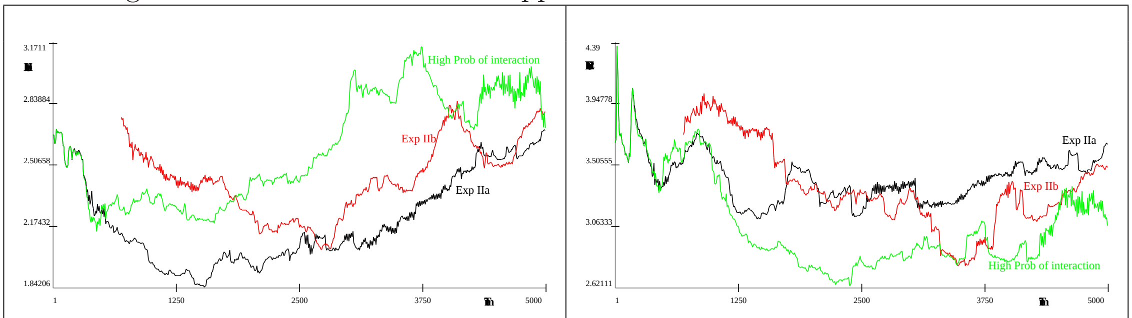
Figure 26: The effect of innovation with heterogeneous preferences on market concentration



(a): IHI compared: sector 1

(b): IHI compared: sector 2

Figure 27: The effect of client–supplier relations on market concentration



(a): IHI compared: sector 1

(b): IHI compared: sector 2