A Generalised Computational Model of Firms Production and Interactions: Emergent Network Structure and Industrial Development

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Abstract

Given the centrality of firms as actors of industrial development and dynamics, our first aim has been to model their production process in a flexible and operational way. Secondly, given the importance of interactions in understanding economic phenomena, the following aim has been to model this process in order to be able to embed firms in an interacting system, and understand their changes as cause and consequences of the interaction patterns. Thus, we present here a first experimental version of a model of production that depends on firms features and resources, which on their own change according to changes in the system in which firms are embedded, provided that firms are central but certainly not the only actors of economic and industrial development. Our broad objective is to use an enhanced version of the described model to understand the processes of industrial development, in conditions in which firms interact both at local and international level. The main question we will try to address is on the role of the local system and the structure of the interactions, on the development of the same locality. This said, in the present work we basically show the structure of the production model, and the way in which we could represent firms vertical interaction under an input-output framework, and how its features affect their 'performance'. We show that the way in which the process is modelled is both extremely flexible, and robust under standard basic economics assumptions. As discussed in a methodological section we argue that those characteristic will be of importance to understand the abovementioned broader dynamics.

Keywords: production processes & industrial development; simulation model; local production system;
JEL codes: C63; O14; L23

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1. Introduction

This paper is part of a broader research that aims at understanding the industrialisation (and innovation) processes in less developed countries, and how their different paths affect growth and ‘competitiveness’. Given the centrality of individual actors and their interactions in shaping those emergent macro conditions, we partly (conceptually) draw on growth models based on micro evolutionary dynamics (Metcalfe, 2000; Metcalfe *et al.*, 2002). Nonetheless, we take into account that firms do not operate in an aseptic environment; on the contrary, they are embedded in a particular institutional milieu that entails framework rules and other organisations not devoted to production. Thus, we aim at understanding how this system changes due to the interaction of local actors, how its properties conversely affect their characteristics and interacting behaviour, and finally, how the relations with the external systems (composed by other actors) are shaped, and conversely shape, the local features. We thus aim at building an agent based prototype that aims at replicating such a complex interacting system.
More broadly, we try to endogenise in shaping the research the elements that render economic processes so difficult to understand, sharing the view of ‘the economy as an evolving complex system (Arthur *et al.*, 1997): i) dispersed agents act in parallel, and the action of each of them, as well as the generated outcome, reflects on their behaviour in the following periods; ii) no global entity controlled[1] iii) different levels of interactions, which only to a certain extent are hierarchically organised, represented by the different recognised organisations and institutions; iv) agents continually adapt to this changing system, also through learning; v) the continuous interaction actually create emergent conditions which are sometimes completely new (innovations); and vi) given those emergent dynamics, which continuously reshape the environment in which the actors ‘live’ there is no such a think like equilibrium, and when it appears it is a transitory condition.

In the present contribution we draw from this general framework[2] and focus on the modelling of the production process, with particular reference to elements that shape and are shaped by relations among firms. The ratio behind it, is that firms central action is production, and their relations and outcomes can be understood if we can build them on an appreciative production process. In brief the model represents i heterogeneous firms, which produce in different sectors combining k inputs (all with h quality features), with a vector of m competencies. Thus, firms are depicted as complex agents, but not as systems of interactions themselves (although there is an interaction between competencies and input, but not between agents). The output is represented in a Lancasterian fashion (Lancaster, 1966), following the conceptual framework redesigned by Gallouj and Weinstein (Gallouj and Weinstein, 1997). In sum, product consists in a vector of different features of a manufactured good. Demand is a function of both price and qualities elasticity, thus partly determines the market share of each firm in the market for final goods.

Vertical interactions between buyers and sellers, both local and foreign, are modelled taking into account the different ways in which production relations can be established, and replicated. The features of the final goods depend on the features of the inputs used, providing an incentive to both users and producers to co-operate to different extents and aims (e.g. knowledge exchange, input’s features definition, etc.) (Lundvall, 1988), reducing their ‘social’ distance. Horizontal interaction can take place when two firms producing at the same level of the chain have a mutual interest in exchanging bits of information (e.g. markets, technologies, knowledge), and the level of appropriation of the information or knowledge is low. The two types of interactions are based on

[1] Although defined boundaries for action exist.
[2] For a preliminary description of the more general framework refer to (Ciarli and Valente, 2003).

different levels of 'trust' and 'language similarity', again measured through a 'social' distance but also on the level of common knowledge base of the agents (i.e. absorptive capacity).

We model the process through a dynamic agent based like computational model in which variables co-evolve, causalities are defined, and the results portray the relevant emergent properties and interactions. We use an Object Oriented language programme based on a C++ platform, designed by Valente (e.g. Valente, 2002), Laboratory for Simulation Development (LSD) (http://www.business.auc.dk/~mv/Lsd/lsd.html).

Given the aim of the paper, it will be organised as following. After the introduction, we briefly describe the *general model* framework, representing the systems analysed, and the considered agents. Thirdly, we describe the formal construction of the *basic production model*, showing few examples of expected results provided by the model. The fourth section describes the way in which the vertical input output process is established. We then depict how the different agents should interact inside the interaction space at different levels, and across different systems, affecting variables and parameters of firms (contained in the production model), thus proposing the future developments of the model. Finally, we discuss the methodological point of view adopted, and we provide some final consideration on the results obtained and the model built. In both cases we consider its suitability for the forthcoming development of the more general model of the local system.

2. The general settings: the theoretical structure of the system

Although in the present paper we concentrate on the description of the production process, and the way in which firms evolve in an aseptic environment, we first briefly present the structure of the overall system for which firms are designed as the driving force[3]. This should allow a better understanding of the production model described further on, and the ratio that have led to its particular configuration.
In the overall model we mainly distinguish four different levels, in a hierarchical order:
- Firm
- Local system
- National system
- Global environment

The four levels can be thought as different "emergent hierarchical organisation" (Lane, 1993), thus as the emergent representation of lower level agents interactions. Nonetheless, the upper levels represent some of the conditions to which the lower level agents react, according to their behavioural rules (routines, etc). Moreover, the emergent systems are themselves interacting agents, which generate the following hierarchical emergent system (e.g. firms interaction shape the LIS and the interaction between the different local systems generate the national conditions). Hence, while firms should be considered as sets of interacting agents (e.g. Aoki *et al.*, 1990), they are themselves agents that interact, although those relations are held by the same agents that compose the firm. The same can be said for the local systems, and so on. Hence, there is a bi-univocal relation between the agents and their emergent properties (which can also be seen as a 'second order' emergent property (Gilbert and Terna, 2000)).
Given the complexity and the infinite structure of the hierarchical systems, we concentrate, and partially model, one intermediate level: the local system. Nonetheless, to do so we need to model it as an emergent structure. Thus, we define a set of agents that interact in the system, and basically distinguish between local firms and local non productive organisations (NPO). While the first are

[3] We derive the concept from neo Schumpeterian economic literature, such as (Nelson and Winter, 1982).

modelled as complex agents in an agent-based model fashion, the latter are exogenously given and do not have endogenous dynamics, only provide local conditions. In short, they can be considered as the scaffolding organisations, described by Lane as those agents that support the overall production system when structured in an industrial district like form (Lane, 2001). Moreover, we consider two spatial dimensions, a local and an international one, shaping the relations between agents at the first hierarchical level: i.e. local firms interact with external ones. Similarly to NPOs, the foreign firms are not modelled as the local ones, as complex agents, considering that we are interested in their impact but not in their evolution.

In all, three kind of linkages are described:
- Local firm - local firm (horizontal and vertical)
- Local firm - local NPO
- Local firm - international firm

The model is not a pure agent based one, as we have dynamics that are not based on agents, but directly on aggregates (e.g. the demand in the final market). Only local firms have the capability to interact with other agents, to decide actions and react to environmental changes. They are in fact modelled as (Wooldridge and Jennings, 1995): i) *autonomous*, there is no controlling power, but each behave according to personal rules; ii) with *social ability*, as they interact with other agents and they can understand each other through some common language; iii) *reactive* to the environment in which they are embedded, and to its changes; and iv) *proactive* toward the environment, taking decision that adapt their aims to environmental conditions and try to change it. Thus, firms' action depend on their neighbours status and action as a conditional probability function, but we differ from statistical (physical) interacting model in two main respects: i) we consider proximity as a dynamic feature, such that agents con change their position with respect to one another (we refer in this case to social and technological values more than to geographical ones), thus changing the type and extent of influence they exert, and ii) we model not only agents' outcome but also agents action and reaction: firms are partially cognitive.

To conclude with the rational of the overall project, the aim of the broad model is thus to frame an 'artificial world' for the analysis of Local Innovation Systems (LIS) and the relations between its actors and with external ones (traders, brokers, suppliers, foreign investors, etc.). We argue that both the Network Structure (NS) and the LIS are evolving entities, which have an important role in explaining the industrialisation processes of a defined system (might be a locality or region). We argue that their initial conditions, the relations with the broader national system, and the way they are aligned with the international networks[4], shape the 'competitiveness' of the whole country (proportionally to their size). 'Competitiveness' refers not only to the single actors' efficiency or to macro indicators, but to the capability of the system to innovate and upgrade, approaching a leading role in 'production' (and innovation[5]). Defining the LIS, we refer to the concept of National Innovation Systems[6] transferred to the local or regional level, and its localised institutions and

[4] We borrow the idea of alignment of networks at different levels (local, national and international) as a key variable to investigate and understand 'successful' industrialisation processes from Kim and von Tunzelmann (Kim and Tunzelmann, 1998).

[5] When referring to developing countries, it is usually difficult to talk about leading (radical) innovators; but we can still consider innovation at the local level, thus relative to the starting conditions. I.e. innovation might be both radical and incremental when considering the single country, but is less likely when considering the international manufacturing system.

[6] Which has been widely defined and analysed, although under different perspectives (e.g. Freeman, 1988; Lundvall, 1988; Nelson, 1993). The central characteristic, which emerges through the various representations, is the view of the industrialisation process as a systematic evolution in which the interaction among the different actors characterises the pattern of each country (also through the interaction with external players).

organisations[7]. We introduce *a latere* the concept of NS, which focuses on the linkages among the local players, in terms of strength, fluidity, extension, flexibility, etc.

3. Production model and interpretation of the results

We describe in the present section the 'engine' of the overall model, a process of firms' production, aiming to describe and operationalise a flexible production function. The scope of this first basic model is to replicate basic results of a production market, with no particular and unexpected behaviour, as it has no endogenous dynamics (i.e. no autonomous decision by the firms as direct reactions to changes in the market and of other firms). Firms react (adapt) to the demand in terms of formation of market shares, revenues and profit, but do not change their strategies when facing changes in the market results.
We also neglect, in the basic description, any direct interaction at the horizontal level, and reaction functions between firms, which produce only in function of the changes in the final demand. Nonetheless, we set the model such that the different relations with other agents, introduced step by step, can affect differently the dynamic of each firm. There is also no exit of firms, which would require further assumption on the financial conditions; firms can produce for a very small portion of the market, being still able to survive. Hence, firms produce a positive quantity as far as they have a share of the market (which never goes to zero), and hence make profits (provided that fix costs are low enough).

3.1 The simple production model

The model represents a group of heterogeneous firms in one sector selling an homogenous competing product. When considering the single sector we refer to goods for the final market The product is homogenous in terms of its final use, but heterogeneous in terms of price and quality features, in a Lancasterian fashion (Lancaster, 1966). The model aims at representing production and market dynamics for those heterogeneous products. Hence, output goods are represented as vectors of quality characteristics (Saviotti and Metcalfe, 1984):

$$\overrightarrow{Y_i} = \{y_{1,i}, y_{2,i}, \ldots, y_{m,i}\} \tag{1}$$

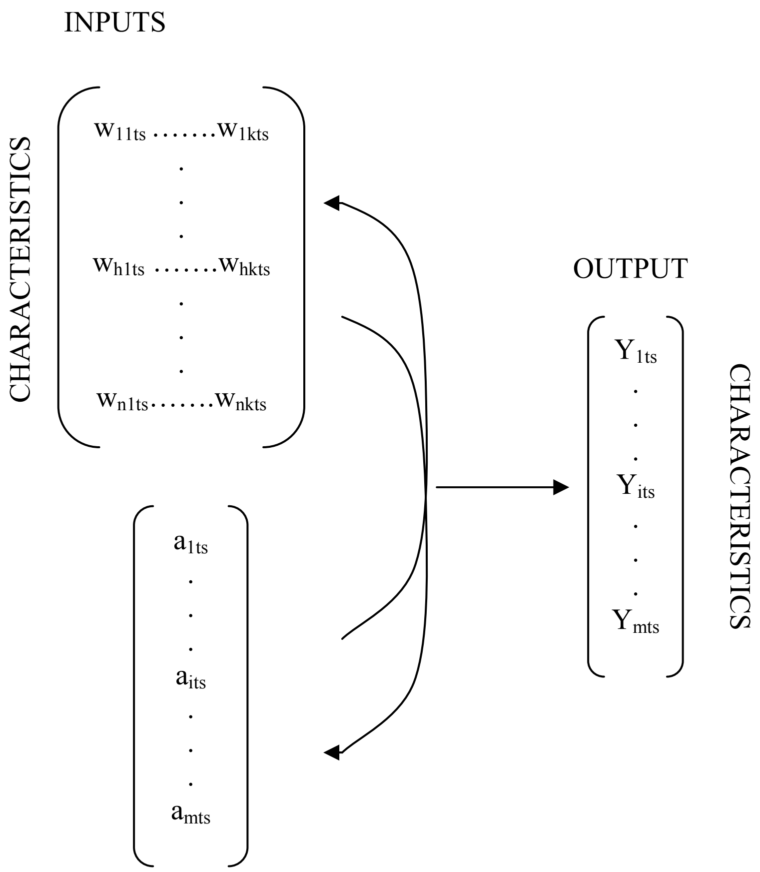
That is, the product produced by the i^{th} firm is defined by a vector of m values, one for each characteristic.

Production takes place by combining inputs with firm-specific competencies. Each firm thus has a certain amount of initial resources and combines them to obtain the final product. Following the framework drawn by Saviotti and Metcalfe (Saviotti and Metcalfe, 1984), and modified by Gallouj and Weinstein (1997), conceptually the output vector of characteristics $\overrightarrow{Y}$ is produced through the combination of a set of vector of competencies $\overrightarrow{A}$ and different vectors of technical characteristics $\overrightarrow{W}$ embedded into inputs (one vector for each input used). The production of one single product requires the use of different inputs (e.g. intermediate, primary goods and capital), each of which can be introduced in the production process given the existence of minimum competencies. We thus adapt the Saviotti-Metcalfe framework depicting a matrix of inputs (h, k), which includes k inputs

[7] In line with great part of the literature, we refer to institutions as the broad set of norms developed along historical evolution (might think as the software component of the system), and to organisations as all the actors that operate in the system, both producing and not, private and public.

and their n characteristics for the production of a final good. Similarly, a matrix A defines the competencies and the characteristics required for the use of that specific combination of inputs (cf. figure 3.1). Moreover, for sake of simplicity, and in order to be able to deal with a 'complex' industrial structure, we apply this framework that has been designed for goods, to aggregated sectors of similar goods. The vector of technical inputs is partially dependent on the competence vector, as the use of certain techniques is subject to the acquisition of a required combination of competencies and absorptive capacities. That is, firms are not able to acquire all values of input qualities, but only up to a certain level, depending on their level of absorptive capacities (Cohen and Levinthal, 1990). Hence, we cannot set high qualities for the inputs, with too low values of the competencies.

Fig. 3.1 – The production function



Source: Adapted from: Gallouj and Weinstein (1997), p. 544

In the present paper, following the model initialisation, the values of the output qualities (in each sector) are computed for each firm i as the combination of[8]:

5 matrices A of k,h $(k \times h)$ elements $a_{k,h}$, where each matrix refers to given competencies m in combining the $k \in \{1 \ldots 3\}$ inputs each with $h \in \{1,2\}$ features, with

1 matrix W of h,k $(h \times K)$ elements $w_{h,k}$, as each firm uses a k number of inputs and each has an h number of quality features, which reflect into output quality features. The result is represented in the following way:

[8] Following this equation, we then suppress the index i identifying the single agent, if not required for clarity.

$$y_m = 1 + \frac{\sum_{k=1}^{K}\sum_{h=1}^{H} a_{i,h,k} w_{i,k,h}}{h \cdot k} \qquad (2)$$

Thus, y_m is primarily an output of the firm general competence m (when matrix components are assumed equal for each firm), and then of the single characteristic of each input, and the associated competence to each characteristic. This kind of modelling allows for a number of changes in the use of competences, which can vary for all inputs (e.g. general learning by doing at the firm level, or change in organisation, etc.) or for specific ones (e.g. increase in capital input quality, imports of specific materials, etc.). We normalise the values of the output in order to avoid having distorting large numbers from the multiplication of factors, which would arbitrarily change the weights of qualities and prices in the definition of market shares and of the final demand.
The demand side has a quite standard configuration: the total demand in the market is determined by the average quality of products across all the firms. The theoretical demand is:

$$D^* = H \cdot \left(1/\overline{p} \right)^{\alpha^p} \prod_{m=1}^{M} \overline{y}_m^{\alpha_m^y} \qquad (3)$$

where H is a constant, the over-lined symbols refer to the average of prices and product characteristics across all the firms (weighted by the quantities), and the α^y and α^p are respectively the elasticity of demand to each characteristic and price, always positive.
The actual demand in each time step is an average between the former time step demand level and the current "target" demand, under the assumption that it takes some time before consumers saturate a market:

$$D_t = s^D D_{t-1} + \left(1 - s^D\right) \cdot D_t^* \qquad (4)$$

The individual firm's demand is computed as a share of total demand proportional to the relative price and quality of its product relative to its competitors. The procedure computes first an index of 'competitiveness' for each firm as:

$$I = \left(1/p \right)^{\alpha^p} \cdot \prod_{m=1}^{M} y_m^{\alpha_m^y} \qquad (5)$$

where the elasticity α^p and α^y are defined exactly as for the demand equation (3). It is clearly possible to release the assumption that consumers respond to market (average values) and firms in the same way, differentiating the individual and general parameters.
Then, the target market share is computed as the ratio of the firm's *i* index over the sum of all firms indexes:

$$ms^* = \frac{I}{\sum_{i=1}^{n} I_i} \qquad (6)$$

The actual market share is again computed as an average between the previous period market share and the "target" market share, under the assumption that competitive changes in products take time before being acknowledged by consumers, and therefore being translated in market shares' changes:

$$ms_t = s^{MS} ms_{t-1} + (1 - s^{MS}) ms_t^* \quad (7)$$

Once the market shares are finally computed, the actual quantity sold by each firm is computed as a ratio of the total demand given by the actual market share.

$$q = ms \cdot D \quad (8)$$

A quantity coefficient β_k determines the consumption of each input for the given level of output production. Thus, the number of factors for certain inputs is fixed for each good (e.g. tires for cars), while the efficiency of input used is given by a quality value of the inputs' characteristic $w_{h,k}$. A reduction in the input coefficient, when possible, is interpreted as an improvement in the production process. The price of the final good is computed as a mark-up over variable costs, assumed to be the result of the only inputs directly used for the production. The total costs for the inputs is then divided for the amount of output to obtain the unit (variable) cost, which is then augmented by a mark-up (*mkp*) parameter to obtain the final price.

$$c^V = \sum_{k=1}^{K} q_k^I \cdot p_k^I \quad (9)$$

$$p = \frac{c^V}{q}(1 + mkp) \quad (10)$$

Finally, given the quality each firm *i* is able to produce, and the price at which it sells the good (which conversely determines the demand in the following period), the profits are given by the revenues minus the sum of variable and fixed costs (c^F):

$$R = q \cdot p \quad (11)$$

$$\pi = R - c^V - c^F \quad (12)$$

The model implements a simple market mechanism that allows the exploration of a wide number of effects and the implications of several interaction which shape the parameters included in the model. For example, it is possible to implement two different mechanisms for R&D: i) increasing the $a_{k,h}$ competencies in order to improve one or more of the quality dimensions of the product (product innovation; ii) decreasing the quantity coefficients for the inputs to reduce the production costs (process innovation); iii) increase the quality of the inputs, searching for better ones, or giving incentives to providers to improve them. In the first case (i), when there is no particular effort in the increase of internal competencies *A*, the quality level of the inputs is directly reflected into a correspondent level of the output. On the contrary, when the level of internal efforts are sufficiently high, the output quality can be increased with respect to the input one.

3.2 Some expected results and their interpretation

The following preliminary results of the model show a 'regular' behaviour of the firms, which reach a steady state in a quite short period, if we consider each time step a production cycle[9]. Given the

[9] Given the methodology adopted time is clearly discrete. We do not consider the discreteness a major problem, but we need to define the entity of time periods to better handle the interaction process. First of all we need to establish 'precedence of causalities' (Valente, 1998) in interactions and variable computations (e.g. do entrepreneurs first look for supplying firms or for the demand features?). Secondly, the same has to be done for the relation between emergent

future implementation of the above model, it is important to obtain sensible and robust results at this stage (e.g. in accordance with standard neoclassic economic theory, when holding the same hypothesis). In fact, we want to be able to exploit the flexibility of the model without incurring in outcomes biased by its construction, when introducing firms behaviour and interactions with other agents (both firms and other). Thus, scope of the presentation of those preliminary results is to discuss on the effects of the different parameters, in order to be able to interpret in the following versions of the model (when endogenous and exogenous dynamics acting on the parameters are introduced) the overall effect of 'complex' changes (changes which entails 'complex dynamics', due to the interaction of the many variables), controlling for well known and verified dynamics.

The main parameters on which the results of the simulation depend, and which are of interest for the direction of development of the model are the i) quality features of the inputs (both price and qualities), ii) competencies of the firm (both as overall competences and process capabilities), iii) the related elasticity in the final market, which permit to distinguish the different markets faced by firms in different sectors and iv) the mark-up, or pricing strategy. The last is introduced as a parameter in this first version, and then endogenised as a short term strategy of the firms.

Before commenting on few selected cases, we provide some general simulation features, which apply to all the initialisations presented, and might result helpful to interpret the results. Input features and prices are reflected in the respective values of the firms' output. Their role ultimately depend on the values of the consumers' preferences given by price and qualities elasticity. For simplicity, we assume that consumers react in the same way to the general values and to each firm changes, and that the elasticity is evaluated with respect to the average of the quality features and not on the single firms[10]. Both differentiations can be easily introduced, although it would increase the complexity of the results interpretation. Moreover, to really add interpretable information with the single elasticity parameters, one should make assumptions also on the types of quality features considered, otherwise they would be interpreted exactly as the average parameters.

Given the way in which the price forms, the input prices play an indirect role also on the final profits, as they actually increase the value on which the mark-up percentage is then applied. As we will observe, this is the case especially when the price elasticity is low and firms with high final prices loose their market shares, but still have enough market to obtain high profits. As a comparison with actual dynamics one might think at the same good produced for two different market niches (high quality and low quality), or to basic products such as petrol for which the elasticity is clearly low, and an increase in the input price alter only slightly the demand function.

Finally, we would like to pinpoint especially one conditional technical feature of the model, which shapes somehow the results through the weighting of prices and qualities, as a function of the preliminary configuration. In the determination of the target demand and of the 'competitiveness' index I, there is a feature that has to be defined by the modeller through parameters setting (α indexes) and which can be tested, and one which is the result of the functional form. That is, given that the number of quality features is higher than one, while the price value is unique, to avoid a strong bias toward the first ones, we have normalised the quality index (see eq. (2)). Still, given that the value of each y_m is always larger than one, it might have a higher weight in determining the market share and final demand, when not controlled case by case.

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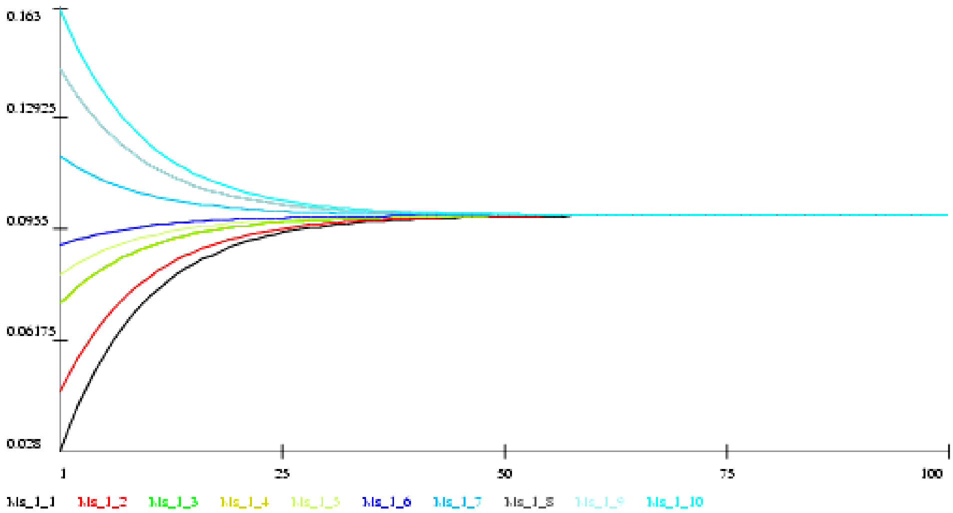
properties and effects on single agents (e.g. do consumers define the aggregate qualities and prices for goods, or they are supply induced?). Hence, in order to be able to manage a certain degree of complexity, with various sequential interactions, each time period indicates a short time (day). During each time step the production process is undertaken and different kinds of relations with the other agents established or continued. Nonetheless, in the further implementation of the structure, decisions on inputs modification, pricing as well as on R&D investment, take longer.

[10] While in certain cases it is more likely that consumers have different preferences for each quality feature, it is also often the case that features are complementary to one another. Thus, it is difficult to observe one of the features highly performing and the others at very low values although firms might prefer to specialise on certain ones (Valente, 2003).

Sim1: the representative agent (or, what the model is not aimed for)
In the first instance, when considering a representative firm (in terms of price, qualities, competencies, input acquired, and the like), there is non possible shift from the perfect competition equilibrium, and when starting from different positions in the market (different market shares) firms tend to divide equally market and revenues (all firms also apply the same mark-up). Accordingly, there is no change in the demand, which is defined since the first period by identical prices and qualities, a part from the market adaptation (given by the smooth coefficient) (Fig 3.2).

Fig. 3.2– Sim1: market shares

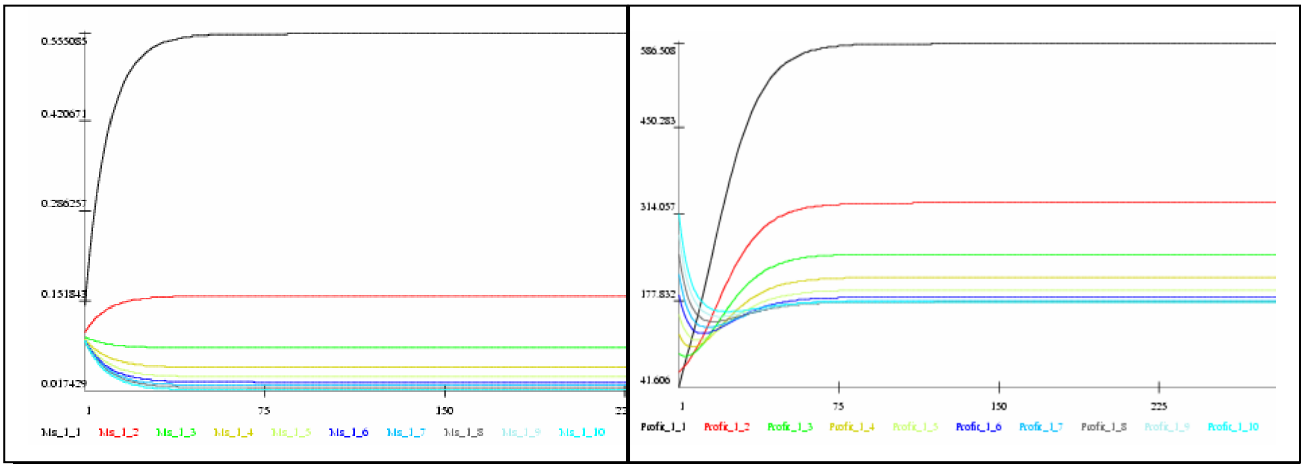


Evolution of market shares through time (100 cycles), where 'ms_1_1' indicates the market share of firm 1 (in the first market, which is the only one considered here) departing from different initial shares of the market.

Sim2: Different input prices and quality with high demand reactivity to prices and low to qualities
We order the firms by input quality features and prices, assuming that when the second are higher thy are also endowed with higher qualities (see parameter settings in appendix). With all the other parameters ceteris paribus, a high sensibility to prices and a very low one on qualities, as expected the firms which gain the market are those who opt for low quality and low prices (e.g. Chinese shoe producers). Given the high sensitivity to prices the last firms sell (produce) a very low quantity which cause lower overall profits, although the value added on selling is higher[11] (Fig. 3.3).
The general conditions of the market also cause an increase of the overall demand (both target and real), as the firms which have the higher weight are the ones that offer a lower price. Accordingly, both average quality and price in the market fall down, as a consequence of the interplay between the demand and supply features (Fig. 3.4). Following the demand increase shown in the figure below, even those firms that loose shares of the market, after a period of profit loss they have a slight rise, interrupted by the demand stabilisation to its steady state.

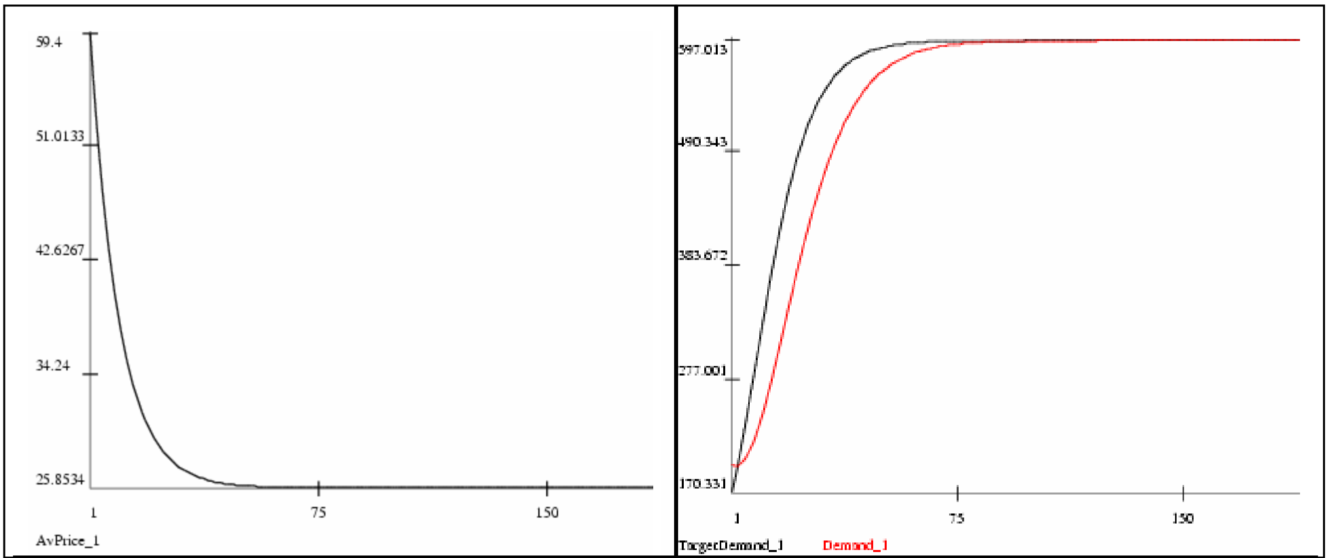
[11] The assumption that firms with higher qualities and prices can also ask for higher final prices (given that the percentage of mark-up is the same) is quite acceptable if one thinks to real markets where only firms in the niches of high quality goods can increase their price, while standardised commodities face a hard price competition.

Fig. 3.3 – Sim2: market shares and profits evolution



When consumer are highly sensible to the price differences, the firms using low quality and price inputs have an advantage which increase their market share and their profit relatively to high quality producers, which are penalised by the prices. Commodities are more suitable for this type of dynamics.

Fig. 3.4 – Sim2: average price and demand dynamics



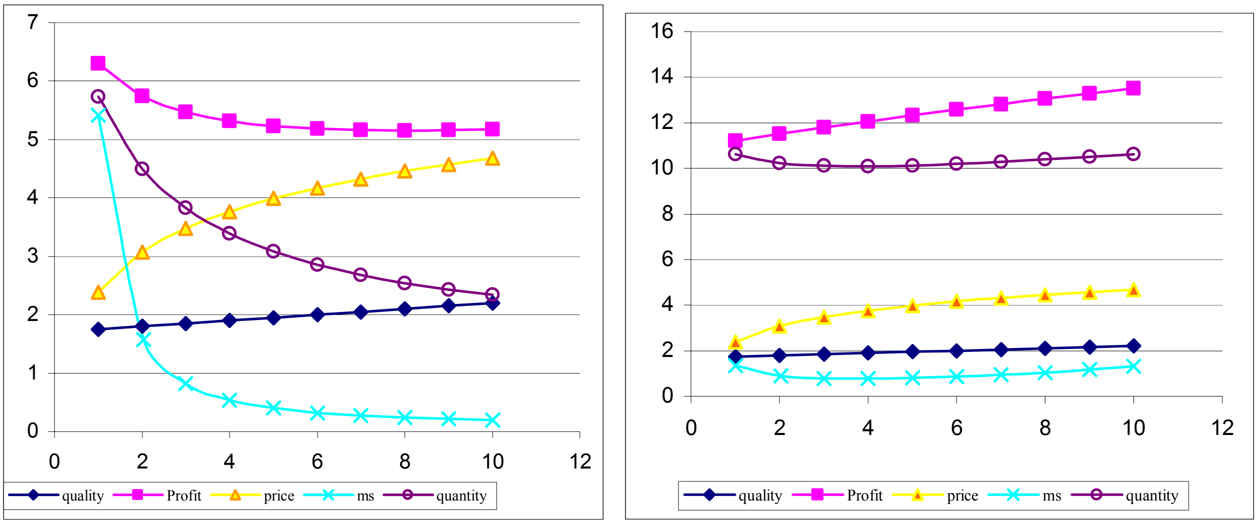
Demand is driven by the firms that acquire the larger share of the market, and can impose their standard as average good: in a market with high elasticity to prices, firms with high price gain shares and reduce the average price.

Sim3: Different input prices and quality with unitarian reactivity to prices and qualities

When, given the above input conditions (same as Sim2), jointly with equal price and quality elasticity set to one, although some of the firms with low quality output are able to gain high market shares, their profits are much lower in relative terms (higher in absolute terms, given the increase in demand), as the consumers prefer to buy high quality goods with price inflated by the cost of the inputs (we are assuming that the higher cost of inputs is correlated with high quality) which lead to higher qualities). Those differences provide an idea of the various possibilities to set the model in order to compare different sectors and their dynamics in different markets. In fact, the different values of elasticity can be attributed to the market conditions (e.g. whether local in a developing country or world market, with higher or lower competition, etc.). The possibility to introduce different preferences for the average market and for each firm, would also allow to consider market segmentation and different niches of competition (again, provided we can specify the nature of the quality features).

We show below a comparison between the firm average values and their relative positions (Fig. 3.5), as the simulation graphs would show dynamics similar to the above ones (Sim2), basically with inverted results.

Fig. 3.5 – Comparison of variables' relative values, between markets with different elasticity



On the x axis are the 10 firms, while on the y axis the average value of the variable for each firm, on the 300 periods simulated. Profits, price and quantities are expressed in natural log values, while the market share is scaled up by ten in order to have comparable order of measure.

In the above figure[12] we note that market shares between firms are much more similar that in the previous configuration Sim2, given that consumer preferences are less defined. As a consequence the quantity sold is similar, but the differences in prices now cause an inverse shape of the profits curve. Those results show some preliminary[13] differences for firms localised in a developing country and producing either for a local or an international market, when selling directly, without intermediaries. Local price elasticity, for goods which are not basic, is on average much higher, while the quality features are rarely considered, by the great majority of the population (conditions in Sim2). This generates an argument for the importance of the export market, although a firm would have then to face a condition of price competition, given its low competencies in production and low availability of high quality inputs, when not imported. It would then be quite intuitive to show the emergence of multiple equilibria, and the specialisation in different sectors (either based on price or different qualities advantages) in which comparative advantages might play a crucial, distorting, role. Here it is of crucial importance the concept of technological complementarities between firms (Durlauf, 1993), and the role of local linkages (Hirschman, 1977), jointly with external ones (Kim and Tunzelmann, 1998), to understand the pattern they can enhance. In fact, some of the conditions, which we assume in this basic formalisation, are actually shaped by the firms settings and its interaction with other agents. In this respect, also the given demand plays a crucial role, which is even greater considering the 'role' of technological imitators held by the developing countries, a position from which it is difficult to change demand preferences, if not through price features.

[12] The Figure compare results obtained with number 10 competencies, and 15 input quality features. As argued before, this change somehow the relative weights of price and qualities, in the definition of the demand and market share. Yet, they do not change the considerations here presented, as the patterns are very much similar when only five competences are included and 2 input features. Nonetheless, one would note that in the latter case the market share curve is almost monotonic, without the convex shape of the one presented in figure.

[13] Part of the aims of the present modelling is to analyse the relations between firms at the local level and firms that buy or produce in the international market, both in terms of production, opportunity and knowledge/technology transfer. Thus those differences will be analysed more thoroughly in a forthcoming work.

Sim4-Sim5: dominant firms

We describe the above preliminary considerations from a different perspective, showing the production dynamic in a locality in which two dominant firms with higher competencies ($a_{k,h}$), lower input coefficients, better (imported) inputs, and lower prices of input relative to their features, compete with local firms that have the same features set in the previous simulations (Sim2 and 3). We show the simulation both in the local market (high price and low quality elasticity) and in the global one (low price and high quality elasticity).

Fig. 3.6 – Sim4/5: market shares comparison with different price and quality elasticity

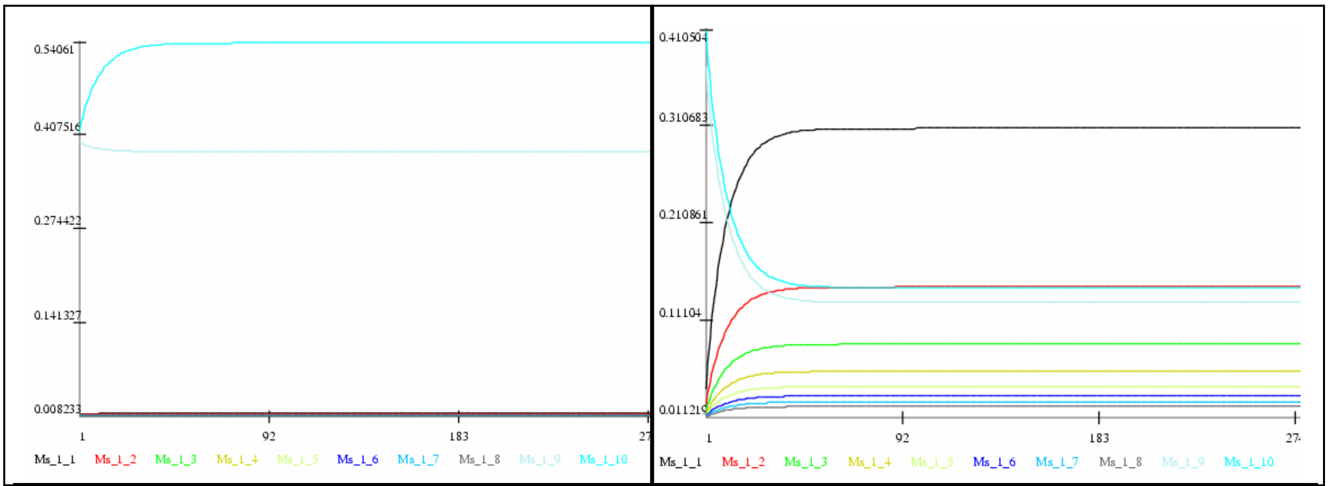


Figure on the left indicates condition in which α^p=1 and α^y=1.5 (foreign market). Figure on the right: α^p=2 and α^y=0.5 (local market).

In the above figure (Fig. 3.6) it is shown that when competing in the international market (assuming there are two advanced companies and eight companies from the selected locality) where the condition of the demand require high performance, the local firms are almost out of the market, if not for a small fraction, which is likely to comprehend the local one. On the contrary, when considering the local market, the high sensitivity to price changes hinders the possibilities for advanced firms to maintain high market shares with higher price and quality goods. Nonetheless, as mentioned before, and shown in the figures below (Fig. 3.7) in both markets profits of the most advanced firms are higher, given their higher final mark-up. When considering the first market condition, this dynamic is again the result of an increasing demand (the demand increases given the increase in the quota of high quality goods and the low responsiveness to price changes).

Fig. 3.7 – Sim4/5: profits comparison with different price an quality elasticity

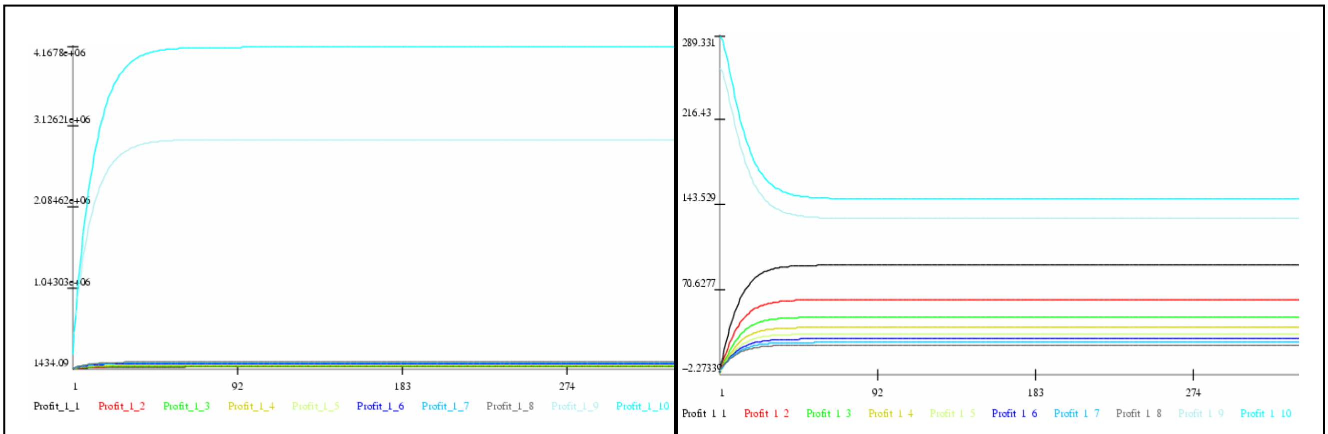


Figure on the left indicates condition in which α^p=1 and α^y=1.5 (foreign market). Figure on the right: α^p=2 and α^y=0.5 (local market)

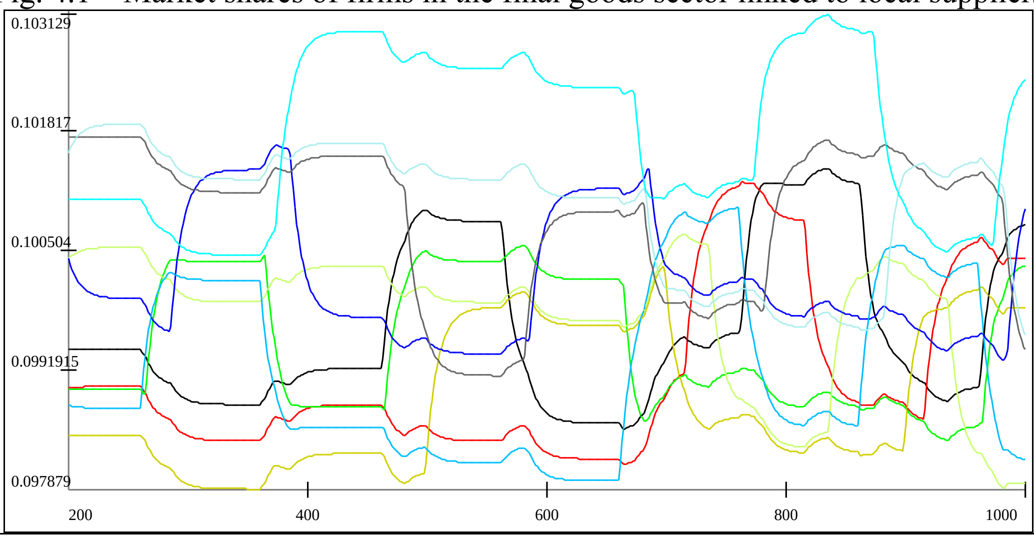
Many other combinations of the parameter settings can be experimented, although we have shown the main patterns of the basic model dynamics.

3.3 short term firm strategies: price changes through mark-up
[allow companies to have a pricing strategy. For example, the mark-up level can be modified to respond unexpected market shares fluctuations. To be added]

4. A model with vertical interaction

One of the most important ways to introduce innovations in a system of production is to acquire intermediate products, or capital, with a higher technological content. In order to allow our model to represent this aspect we need to consider explicitly the vertical relations among firms in different markets. We begin by considering two markets, respectively for a final consumption good and for a generic "input", an intermediate product used by firms producing the final consumption good. Each market contains several firms, each defined as described above. At any time, each firm in the final good market uses as current supplier of the intermediate good one of the firms in the input market.
The major innovation of the model consists in the steps determining the quantities produced by firms in the input market. In fact, these firms assess the amount of production needed at each time step from the orders received by the final good market. In other terms, while the total demand for the final good is determined directly by the consumers' behaviour (as a function of the average price and qualities of the product), the total demand for the input market is obtained indirectly by summing the amount of inputs required from the downstream sector.
As an exercise to test this extension of the model, let us consider a simulation where 10 firms in the final good sector are initialized with slightly different values of capabilities (randomly drawn) and identical mark-up. When these firms use the same input supplier, they obtain slightly different market shares because of their differences in the qualities and costs of their competing products (as it is the case for the simulations discussed in the previous section). We add an input sector composed by two firms, offering the same input product with slightly different qualities, again determined by small differences in their capabilities. The final sector firms are allowed to switch the supplier any given number of time steps, selecting randomly one of the two input producers. The probabilities of choosing the supplier are proportional to their index of competitiveness, as described in equation (5). The result of this test exercise are shown in the figure below.

Fig. 4.1 – Market shares of firms in the final goods sector linked to local suppliers



Market shares of the final good producer, resulting from the switches between two different input producers.

Figure 4.1 shows the time series of the market shares for the producers of the final good. The quite variegated dynamics are due simply to the modifications to the qualities of the competing products due to the use of the two different inputs. Such simple operation generates the complicated patterns because the same firm with the same input supplier will see its relative position (i.e. the market shares) at different levels depending on the choices of the other firms. In any case, the average results of the firms over the whole period largely depends on its own qualities.
The model described so far can be considered a complete "production" model, representing how production and trade is carried on in vertically related markets for heterogeneous products, both final and intermediate. The results produced by this version of the model correspond to what one expects from such a model: competitiveness of a firm depends on the quality level of its product as compared to that of competitors, with consumers' preferences assessing the relative importance of price and other qualities. Moreover, the model explicitly exposes the role of the internal capabilities of firms used to transform the inputs in the output, both in qualitative as well as quantitative terms. Such model will therefore permit comparative studies on the effects of different development patterns of the capabilities. In the next section we describe some of the issues we plan to consider to extend the model including the endogenous knowledge development of firms.

5. The missing elements for the structure of the system: application of the model, a view on the future development

In the present section we briefly sketch stylised interaction patterns and endogenous behaviour of firms, which we are implementing departing from the above described basic production structure. In a sense we immerge the production process into the system briefly presented in section 2 and move toward the 'more agent based' structure. In the first instance we describe the remaining agents.
Local NPOs are distinguished according to the level of interaction with firms in providing the services. i) Some are available to all local firms, without direct interaction, and shape some of the local conditions (e.g. educational; partly R&D organisations); ii) a second category of NPOs provide services only to the firms loosely related to them through the payment of a fee (e.g. interfaces for R&D and external system; some BDS); iii) finally, a last group provide services only following a direct interaction (e.g. R&D organisations).
Concerning the first type (i), educational organisations increase the quality of labour input for all firms, with a higher weight for specialised workers. That is, an increase in education supply shifts the overall distribution of education and skills to the right. Similarly, R&D organisations release some of the knowledge produced through self financing, which is freely available at the local level, and which increases competencies (weighted by absorptive capacities – i.e. previous competencies). In the second case (ii) interfaces between firms and R&D organisations provide knowledge only to firms that are affiliated and pay a fee in change of the knowledge provided. Thus, the payment of the fees reduces some of the operational costs that firms would have to sustain individually (Squazzoni and Boero, 2002), and increase the probability that they upgrade. Similarly for other BDS which might be included. Finally (iii), some of the firms directly interact with R&D organisations, modelled jointly with internal R&D processes, i.e. *una tantum* investments that increase competencies, as a mid/long term strategy to increase firm competitiveness in the market (as opposed to the short term price policy).
Some of the organisations, such as chambers of commerce and category associations are modelled as to reduce horizontal interaction costs between firms and increasing the flow of information (through an increased social proximity).

Vertical interactions are only part of the relations that undergo in a local system, and the 'easier' to model, given the required input output system of a an economy with a minimum level of division of labour. Nonetheless, in any local system there is a certain extent of horizontal relations, which go

beyond the pure competition, and strategic behaviour of firms. The different local institutional conditions shape in different ways those relation on a continuum that goes from the industrial district type mixture of co-operation and competition, to an oligopolistic structure of non colluding firms. We try to abstract from the first, which assumes the presence of strong social capital, trust between agents, strong common values and non written behavioural norms (e.g. Becattini, 2000; DeiOttati, 1995), elements which are mainly idiosyncratic and difficult to measure and replicate.
We distinguish two types of horizontal interactions: pure information exchange and direct collaborations. Among the information that might be acquired by competitors there are input availability, market dynamic, process of production, competencies and technological capabilities, ordered by appropriation efforts. Hence we distinguish among:
- Input and output markets: given the low appropriability of this information, it is acquired by neighbouring firms when the 'social' distance is medium. Thus, it diffuses in the system quite fast, and increases the number of available input providers.
- Production process (medium appropriability): Techniques used by firms in the production process are less easy to copy as they might be intentionally hindered by firms, if acquired from external sources or endogenously developed, and unintentionally hidden as tacit knowledge. This is not the case when they are provided by local NPOs. Thus, this kind of knowledge can be acquired when 'social' distance is low, and depends on the extent of the difference in knowledge assets between the 'neighbouring' firms.
- Technological competencies and capabilities (high appropriability): in the case in which knowledge is hindered, two scenarios might present, i) one in which there is one firm clearly ahead, and ii) another one in which the two firms have similar competencies. In the first case, part of the technical knowledge is available to nearby firms with a probability decreasing as distance increases (spillovers). When the second case (ii) occurs, we assume two different types of firms, the ones which are likely to share, and the ones that are not. When two firms of the first type are near, the two A vectors are compared, and the non-overlapping characteristics are exchanged. If the exchange of competencies is high enough, the two firms maintain a technical exchange routine for the following cycle. This activity is dropped when the difference between information transferred from firm A to firm B and vice versa, passes a lower bound (one of the firms ins not exchanging) for more than two consecutive cycles (one of the firms is free riding, or anyway for the other the exchange is no more convenient).
Among the activities that might be shared between firms we consider i) R&D, and ii) investment in capital goods. When investing in R&D to increase competencies, firms might decide to do it joining resources with another firm in the same sector. If this is the case, fewer resources are needed to reach the same result, but each of the firms will be able to use the increased capabilities. The disadvantage, compared to individual research, is that also the possible increase in market share is distributed.

Foreign buyers represent one of the market channels for local firms, given that they can achieve a minimum level of goods' quality. The relation between the local producers and external buyer is modelled in the same way as the input output relations established locally. Nonetheless, the profits from such a market are higher than from the local one, even if future dynamism depends on the relation established between buyer and supplier. When completely hierarchical, suppliers have little opportunity for endogenous upgrade, and have to wait buyer decision to change the production. The governance structure thus shapes the kind and pace of technological transfer (Gereffi and Kaplinsky, 2001). On one extreme supplier is provided with high quality goods, and the minimum necessary capabilities to manage them. On the other, technological capabilities are continually increased. Thus, also the extent to which the improvements trickle down to local producers, depend on whether the inputs are completely supplied by the buyer, or the choice is left to supplier, which can co-operate with its providers.

6. Discussion on the Methodology of Simulations in Economics

The use of simulation models in theoretical economics is quite a controversial subject, and the more so for the models presented (and suggested) in this work. Traditionally, two types of simulation models are normally accepted as methodologically rigorous. A first type of models consist in building a quantitatively realistic representation of some real system, and is used to forecast the state of the system after some time. These models can be evaluated with the traditional statistical tools testing for their adherence to the data of interest, and their results are judged according to the same criterion. For example, such models are used to study the behaviour of turbulent fluids. Concerning economic subjects, these "applied" models abound in the offices of central banks or consultants, willing to forecasts future directions of large or small systems.

A second type of simulation models concerns abstract systems that the standard set of analytical tools cannot describe. The simulation model provides a numerical estimation of the model properties, and the evaluation of the model is judged according to the robustness of the properties of the system against different parameterization and/or random events. Example of these models became popular in physics as the "Montecarlo" simulations. Like the mathematical theorems that such models surrogate, one does not necessarily need to understand the proof for appreciating the results.

In both methodological approaches described above the models themselves are considered as "black boxes". Once the code has been certified as correct (i.e. containing no programming error), all one is interested into is the input and output of the program, and the interest focuses on the relation between the two sets of data. Our approach is instead quite different. We use initialization that we consider "sensible", without being interested in using data as close as possible to a specific historical of geographical evidence. And we do not search for general properties of the model, to be found within a large part of the parameter space. Instead, we "open" the black box in order to study how the assembled elements of the model interact through time to produce the results. It is the explanations of the results which are of interest, rather than the results themselves. And it is the explanations that will be evaluated as more or less interesting, in both sense of being unexpected and relevant for understanding real events.

Note that the methodology we used here is not alternative to the two mentioned earlier. One may actually apply all the three methodologies at the same time building a model that: i) closely represents a real system; ii) provides robust general properties, and iii) provides explanations for those general properties. Obviously, the right methodology to use depends on the goals one pursues: our goal is to set the stage to understand the mechanisms of creation (or failure to do so) of sustainable growth of knowledge in a productive system. This perspective does not require a strict adherence to a specific reality, since different contexts provide widely different measurements, or even definitions, of knowledge. Nor we claim to provide universal laws of economic systems. Therefore, a qualitative and partial analysis provided by simulating a simplified system suffices for our goal.

Given the particular structure of the proposed methodology we may refer to it as *qualitative simulation modelling*. The goal of such methodology consists in analysing how particular configurations of the model emerge during a simulation run out of the interaction of the model elements. Referring once more to the terminology proposed by Lane (Lane, 1993) we may say that qualitative simulation modelling is based on the study of the *emergent properties* of a system. In particular, we want to identify the explanations for such phenomena by replicating them in a simulated model and identifying their determinants. There may be two classes of explanations that can be conceptually considered, although most of the times they appear together: temporal and aggregative explanations. Temporal explanations consists in the temporal sequence of events that give rise to the emergent properties. Aggregative explanation consists in the list of the components making up the aggregate phenomenon. As already mentioned, these two classes of explanation are

usually intertwined: an explanation is provided by listing a set of elements, their properties and their dynamics through time, providing an explanation for an aggregate property of the system.
The relevance of qualitative simulation results can hardly be measured by the usual instruments used to assess quantitative models, like the degree of fitting available data or robustness. However, this *un*-scientific approach does not depend on the method of research, but on the subject to which it is applied. The proposed methodology finds a natural application for research questions that pose the attention on *how* given phenomena occur, rather than on *what* is going to occur. In these cases, computers are a unique instrument to replicate, in a controlled environment, some of the complexity observed in the reality. A mere replication of some quantitative phenomena does not contribute to the increase of our knowledge of the real phenomena, if we cannot distinguish *what* combination(s) of elements cause it. While understanding the unfolding of the complexity in the artificial system can teach us something about the events taking place in the real world (and eventually be able to aqpply this knowledge). The reason is that in the vast majority of cases the patterns observed in the real world do not identify a unique generation mechanism. Only if we obtain a generation mechanism that, *both*, produces the patterns observed *and* is consistent with other related phenomena, then we can claim some support for our proposal. According to this approach, the assessment of a model does not require statistical measures, but *only* the possibility of convincing the audience of the existence of the purported explanations.

Using simulation models consists in building artificial representation of portions of reality. This activity alone is worth attention because forces us to express rigorously concepts that frequently are defined in a pretty vague terms[14]. For the present version of the model we limited ourselves to study quite trivial types of results, and we checked that their generation reproduces the explanations normally used in elementary textbooks. Even in this stage, the mere attempt to provide a working representation of elementary economic events, forced us to devise some less-than-elementary computational structures. These difficulties stem from the ways standard economics is generally taught in undergraduate courses. We are told the *properties* of economic systems, or agents' behaviour, but we are not even suggested how they actually function. Instead, a computer program consists of instructions to be executed, with the properties being the results of the computation. Our experience, shared by many simulation modellers, is that the very reasoning about the design of a model is a highly productive stage in terms of economic theoretical research. In fact, one cannot express in a computer language inconsistent statements, or forget to define elements used in other parts of the model, as one is allowed when describing verbally a model. Even mathematical representations highlight possible inconsistencies only during the elaboration of the model's equation. The very use of a computer language is a rigorous test of the viability of our theory, even before the first test run is executed. It is very frequent the case of adjustments, even radical, of a model caused by errors and mis-specifications emerged only when the model begins to be implemented.
Another advantage of simulation models consists in the possibility to build up gradually a complicated model starting from simple components (simple sub models). For example, our model already generates results that would be difficult to interpret, it we did not develop gradually the different parts of the system. Testing each and every new equation and the changing to the overall results after the modification guarantees both that the new part is error-free, and that we can understand the results. However, this aspect relies heavily on the kind of language used for the

[14] See, for example, the concept of local system of production, which can be defined as a cluster, district, milieu, local innovation system, and so forth. Those concepts are used to promote industrial development in developing countries, but, having understood the theoretical background underneath, one would ask, on the basis of which elements they are implemented, a part from idiosyncratic learning by doing? Following the Italian district tradition of the seventies, the English district tradition of the 19th century, the clustering dynamics of biotech industries…? One should then carefully analyse which type of linkages endorses innovation (Staber, 2001), and how they can be promoted. Things complicate much more if we expand the system toward relations that are external to it, but which have to be taken into account.

implementation of the model. Technically, any computer language has the same power of expression. In principle one can choose whatever language and this should not affect the model represented or its results. However, experience shows that some languages are more adapt than others for simulation models. Object Oriented languages (originally designed on purpose for simulation models) have proved themselves to be the most adequate choice because they allow an easier modularization of a program, which, in turn, provides higher robustness against modifications due to error-fixes and extensions. Such questions may seem not relevant for economists, in that one may consider the implementation of model a mere technical task, to be delegated to an expert technician. After all, many economists (with little mathematical knowledge) rely on professional mathematicians (with little or no economic training) to produce theorems. The economist is not interested in the proofs, as long as these are confirmed to be correct. However, for the kind of use of computer models proposed, this is not possible. In fact, we put forward that precisely in the technical inner workings of the simulation program lies the interest of the model. A technicians, however a good programmer, cannot have the sensibility to appreciate the economic relevance of the model elements or behaviour.

While suggesting that economists should write their own simulation programs, we do not sustain that they need to become sophisticated programmers. In fact, a simulation program, like any program, is made for 90% of technical code, meant to deal with interfaces of various nature, and only a small portion of lines directly expressing the model dynamics. Writing a model with a generic computer language forces the programmer to write a whole program, which may require even some advanced technical skills. But if one limits himself to write only the code strictly related to the model's scientific content, the task is much easier, in most of cases involving only the capacity to express few algebraic operations and logical statements.

Concluding this paragraph, we have sustained that simulation models need not necessarily to produce a quantitatively convincing replication of reality, but that can be used to understand complex patterns in a controlled environment in order to shed light on similar events in the real world. Such knowledge takes the form of explanations, either temporal or aggregative, of configurations assumed by the model. The methodology proposed implies that economists get involved in the technicalities of building simulation programs. This implication, though crucial for extracting scientific knowledge from the models, does not require a high level of programming skills.

7. Final considerations

We have presented a computational model representing the production mechanisms of vertically related markets for heterogeneous products. The model explicitly represents the production process as the application of the firm capabilities to the inputs in order to determine quantity and qualities of the output. The exercises presented show that the model produces the results one expects once standard assumptions are applied. That is, keeping constant the capabilities, the performance of competing firms depends on the relative qualities of their respective products, with consumers' preferences determining the relative importance of different qualities.

The way in which firms produce and the process of trade are represented in a very detailed way. For example, there is a specific parameter indicating the effect on each output characteristic of one input's characteristic. The model is therefore a huge one, with thousands of parameters available for initializations. The exercises presented in the paper show that nevertheless the model is very "docile", producing results that can easily be traced back to specific properties of the model equations and/or initialization.

The power of the present version of the model resides in its manageability. Notwithstanding the dimension of the model, we can easily study the patterns produced by the model and trace them to their motivations. The next stage of the development of the model consists in endogenizing some of the parameters concerning the knowledge development of the market and building an interaction structure, as briefly described in section 5. Alternative production structures will be introduced, allowing for a comparative study of the results they produce in terms of levels and sustainability of knowledge growth and processes of industrial development. These future exercises will not only aim at producing more realistic patterns, but will be used to study the chain of events responsible for the emergence of specific phenomena, as suggested in the simulation methodology we called *qualitative simulation modelling*.

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APPENDIX A. PARAMETERS AND INITIAL VALUES DEFINITION AND SETTING OF THE SIMPLE PRODUCTION MODEL

Following is presented the list of the parameters used in the various equations, not always specified along the text, with the values attached in the different simulations.

Parameter[1]	description	all firms	sim1[2]	sim2[2]	sim3[2]	sim4[2]	sim5[2]
H	Constant of the demand (eq. (3))	20000	--	--	--	--	--
Demand (1)		--	59259.3	500	500	500	500
s^D	1 minus rate of adjustment to target demand	0.9	--	--	--	--	--
s^{MS}	1 minus rate of adjustment to target market share	0.9	--	--	--	--	--
α^p	Price 'elasticity'	--	1	2	1	2	1
α^y_m	Quality 'elasticity'	--	1	0.5	1	0.5	1.5
C^F	Fixed costs	--	100	10	10	10	10
p (1)	Initial price	--	10.8	30	30	30	30
mkp	Constant mark-up	--	0.2	0.2	0.2	0.2	0.2
ms (1)	Initial market share	--	0.02 0.04 0.07 0.07 0.08 0.09 0.12 0.15 0.15 0.17	0.1	0.1	0.01 (x8) 0.4 0.44	sim4
a_{hk}	Firms' competencies	--	1	1	1	0.7 (x8) 1.3 (x2)	sim4
β_k	Input quantity coefficient	3	--	--	--	3 (x8) 2 (x2)	sim4
p^I_k	Input price	--	1	1 1.5 2 2.5 3 3.5 4 4.5 5 5.5	sim2	1 1.5 2 2.5 3 3.5 4 4.5 5 5	sim4
w_{kh}	Input quality features	--	1	0.75 0.8 0.85 0.9 0.95 1 1.05 1.1 1.15 1.2	sim2	0.75 0.8 0.85 0.9 0.95 1 1.05 1.1 1.4 1.5	sim4

[1] Into parenthesis the number of lags of the initial value fort he lagged variables.
[2] When more than one parameter is indicated, they represent the different values attached to different firms.