STRUCTURE AND BEHAVIOUR OF A TEXTILE INDUSTRIAL DISTRICT *

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Abstract

This article presents a model of the structure of information fluxes that underlie the creation of production chains in a textile district located in Prato, Tuscany, central Italy. Contrary to most textile districts in western Europe and north America, Prato did not extinct once average salaries in the region rose well above the world's lowest standards. The reason is that Prato was able to switch from a competitive advantage based on low prices to a competitive advantage based on aesthetical features and variety of textiles. Analysis of the structure of production chains can explain the behaviour of the district throughout its evolution. The model reconstructs interactions of ten types of Pratese firms from 1946 to 1993 in scale 1:1.

1 Introduction

Industrial districts stand out as a counterfactual evidence to the general pattern of the evolution of industries. Industries exhibit a large number of small firms when they are in their infancy, but since most profitable firms tend to increase

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their market share, mature industries are generally characterised by monopolies and oligopolies. Industrial districts, on the contrary, are geographical clusters of a large number of small firms that show little or no tendency to increase their size. Evidently, some factor must counterbalance the economies of scale that larger firms would enjoy.

To some extent, the explanation lies in tax evasion, labour exploitation and costs-saving environment pollution. It is possibly not a chance that industrial districts can often be found in low-income countries, where a large part of the economy escapes fiscal controls and the laws that should protect environment and labour are poorly enforced, if they exist at all.

However, this is not the whole story. Some industrial districts are well alive in high-income countries, and compete successfully with similar districts that are located in low-income countries. The Prato textile district is one such case.

Prato is a town near Florence, Italy, where tradition of textile manufacturing goes back to the Middle Age. At the end of the XIX century a few wollen mills were already operating in the area, and textile manufacturing expanded throughout the first half of the XX century. However, it was only after WorldWar II that a real textile district emerged.

Since the 1950s, some woollen mills found it profitable to lay on to handworkers the jobs that exceeded their productive capacity. When demand was high these handworkers could set their whole family to work, while they did not have to pay idle workers when no orders came. In this way, woolen mills could meet demand peaks with a productive capacity tailored to demand throughs.

During the 1960s and 1970s this process accelerated, extending from handworkers to small firms with a few employees. At the end of the 1970s Prato arrived to count more than 10,000 firms directly or indirectly related to the textile business. Most of these firms had a very small size and carried out a brief portion of the production process.

During the 1980s, a deep crisis stroke Prato. Experts had good reasons to claim that textile production was no longer feasible in a region where income had grown up to the world's highest standards, and that textile production would move away from Prato.

However, this did not happen. Contrary to all expectations, Prato managed to recover during the 1990s, and it is well alive by now.

Prato is now a very diferent district from the one that existed in the 1960s and 1970s. It is less typical a district, both because some concentration did take place and because it is no longer a self-contained productive area. Nevertheless, it is still a highly integrated system of thousands of textile firms.

To some extent, Prato recovered because it was able to exploit a cheaper labour force than the one that is generally available in Tuscany today. On the one hand, Pratese firms either learned to purchase intermediate products abroad, or they moved abroad the early stages of their production chain. On the other hand, massive illegal immigration from low-income countries provided cheap and unregulated labour.

However, if cutting labour costs would be the main determinant of Prato's recovery, then all of production had moved to low-income countries. This has been the fate of most textile industry in Western Europe and North America, but not of Prato.

2 From Price Flexibility to Features Flexibility

At its beginning, Prato produced low-quality, low-price textiles. In particular, Prato specialized in wool regeneration.

Prato used to collect rags from all over Europe. Once in Prato, rags underwent a series of chemical and mechanical processes that transformed them into regenerated wool. Regenerated wool is of lower quality than virgin wool, so it was used to produce low-quality textiles. Textiles produced in Prato were very similar to one another, and lack of differentiation brought firms close to perfect competition.

The small size of most firms was of paramount importance for the competitiveness of Prato as a whole. On the one hand, firms that were run by one single family could follow the vagaries of demand by resorting to "self-exploitation" of family members. On the other hand, competition of a large number of small firms that produced undifferentiated goods ensured low prices.

The above picture holds up to the 1980s, when Prato began to suffer from competition by similar districts located in developing countries. Prato's products were of low quality, but they were no longer so cheap. Common sense suggested that major Pratese firms had no choice apart from moving production abroad.

They did it, but only to a limited extent. Only the first links of the production chain moved away from Prato. These are the processes where little quality and little variety can be added to a textile, operations that are carried out in exactly the same way everywhere in the world.

On the contrary, operations that are carried out at the end of the productive chain expanded into a major component of Prato activities [1]. These are the processes where a tissue acquires its distinctive features, including colour, pattern, hairiness, brightness, and tactile characteristics [6]. The range of features that a tissue made in Prato can exhibit underwent a tremendous expansion, and the many textile firms in the area learned to provide buyers with countless options of features combinations.

Today, Prato is successful because it has been able to switch from price flexibility to features flexibility. Its traditional structure of a large number of family firms is still there, but these firms now compete on taste and variety, rather than price.

Since the 1990s, Prato is basing its competitive advantage on its ability to provide anything a buyer may request, in a reasonable time, and in lots of any size. However, Pratese firms do not merely execute customers's commands; rather, they are highly appreciated for their creativity and taste [4].

Apparently, the only weakness of Prato regards the reliability and constancy of the quality of its products. In fact, since flexibility is achieved by means of competition of a large number of firms, customer-supplier relationships are quite unstable at any levels of the production chain. Consequently, quality may vary from a production lot to another because intermediate producers may have changed, and because occasionality of business relationships favours uncorrect behaviours [7]. However, Prato is trying to overcome this inconvenient by means of very detailed surveys of technical faults that could help identifying problematic areas [3].

3 The Structure of Information Fluxes

Since the aggregate behaviour of industrial districts exhibits features that its component firms do not have, and since these features derive from the interactions between component firms, it has been suggested that industrial districts resemble self-organizing, connectionist systems like e.g. neural networks. This analogy is attractive but — at least as far as it regards Prato — it needs qualifications.

Self-organizing, connectionist systems are based on free circulation of information between a huge number of units, e.g. neurones in a neural net. The idea is that a large number of simple components can generate a complex aggregate behaviour, depending on the structure of the connections that the components establish with one another.

The crucial issue is that if components are very simple, very many, and free to connect to one another, information circuits can establish. That is, the components of a connectionist system can create loops where information — at least in principle — can circulate indefinetly. Since information circuits arise spontaneously, one speaks also of *self-organization*.

If information circuits arise, a connectionist system has the ability to store information even if its components do not. Information is stored in the system in the sense that it circulates indefinetly along a loop, although it is not stored by any of its components. In this case one says that the system has a *distributed memory*, whereas its components may eventually implement a more traditional *localized memory*.

However interesting the above concepts might be, their application to the Prato textile district is not straightforward. In fact, connectionist systems require that information is free to circulate. On the contrary, in Prato information flows along a structure that is strongly hierarchical.

Information concerning new technologies circulates quite freely within the Prato district, also because technologies are not of paramount importance for its firms. Commercial information, on the contrary, is strictly private. This information is crucial for Pratese firms, and this information flows along hierarchical paths [5].

Similarly to many other industrial districts, production is organised by a special class of agents, herein called the *middlemen*. A middleman can either be one of the larger woollen mills, or a single person who organises the activity of other firms. In this last case the Pratese jargon employs the specific word *impannatori*.

Who wants to buy in Prato, he asks a middleman. If the middleman is a woollen mill, it attempts to fulfill the order with its own productive means. If the order exceeds its productive capacity, or if the middleman is an *impannatore*, it calls several small firms in order to carry out specific production phases. Wares do not need to pass physically through the middleman; on the contrary, they are generally transported directly from a firm to another. However, it is the middleman who decides which wares must be transported where.

For a middleman, nothing is more crucial than that the identity of the final buyer remains secret to the firms that he contracts. Otherwise, contracted firms could sell directly to the final buyer.

If a contracted firms is not able to fulfill the whole order, the above structure of information repeats itself. In fact, a contracted firm behaves towards a subcontracted firm just like a middleman behaves towards a contracted firm: a contracted firm will never tell a subcontracted firm which middleman placed the order in the first place, just like a middleman will never tell a contracted firm which buyer placed the order in the first place. In principle, this structure can repeat itself over and over like a fractal.

Information flows along hierarchies of middlemen, contracted firms that act as middlemen towards sub-contracted firms, sub-contracted firms that act as middlemen towrds sub-sub-contracted firms, and so on. Free circulation of information does not exist in Prato. Consequently, this district is incapable of building loops where information can circulate indefinetly.

Prato cannot have a distributed memory, it cannot store information if its component firms do not, and it cannot exhibit any behaviour independently of the will of its component firms. Prato is not a self-organising system. It is not a place where firms meet randomly, put orders to one another, and the final outcome is a finished product that had not been designed by anybody.

However, the overall behaviour of the district is not determined by middlemen alone. Production can be organised in many ways, and choosing a way or another ultimately depends on availability of firms to contract. Thus, ultimately all Pratese firms contribute to shape the structure of Prato.

Prato is not a self-organizing system, but it is not even a hierarchy that behaves according to the boss's will. Its behaviour results from the interplay of thousands of firms, though some of them have a more important role than others. The structures these firms build when they organise production chains determine the behaviour of the district in each historical circumstance. The model presented in this article aims to compare the evolution of the structure of production chains with the historical phases Prato went through.

4 The Model

There exist no data concerning exchanges between firms within the district, neither in money terms nor in physical magnitudes. Similarly, data concerning the size of firms are either fragmentary or too aggregate. The only disaggregate data that cover a long time span are the number of firms for each productive phase, from 1946 to 1993 [8].

Unfortunately, we neither know how large these firms are, nor how much they exchanged with one another. However, we know that they must have exchanged information in order to produce and exchange goods.

Now, let us assume that small firms process smaller lots than large firms. If this is true, it follows that the number of orders that firms place to one another is independent of their size. This is clearly a very rough assumption; nevertheless, it is quite reasonable as a first approximation.

Thus, let us make a model where firms meet and exchange information. Evolution of the structure of production chains with time will be compared with performance of this district from its infancy in the 1950s through its expansion in the

1960s and 1970s, to the crisis in the 1980s and the ensuing recovery in the 1990s.

Let us consider the following ten types of firms:

1. Traders of Raw Materials;
2. Rags Collectors;
3. Carder Spinnings;
4. Comber Spinnings;
5. Warpers;
6. Weavers;
7. Dyeing Plants;
8. Finishers;
9. Trader of Finished Products;
10. Middlemen.

The above firms have been chosen both because they include the most important production phases carried out in Prato, and because their relative number varies a lot with time. In this way, interesting dynamics should be obtained.

Since we do not know the real geographical locations of firms, we cannot reproduce physical space. Furthermore, in a model that wants to represent information fluxes, physical space matters only indirectly. The crucial notion of distance is rather one of information proximity in terms of circles of acquaintances and easiness of communication. Unfortunately, data regarding information proximity are not available as well. Thus, initial distances between firms will be chosen at random and the subsequent movenents of firms will obey random distributions.

The model works following the hierarchical information structure described in section 3. Traders of finished products place orders to middlemen, who organise production. Middlemen organise production by arranging firms into production chains. Subsequent hierarchical levels will not be considered.

Middlemen cannot combine firms in any order into production chains of any length. On the contrary, technological constraints restrict the set of possible choices to eleven production chains of various length and composition [2].

Chains may vary from one another because many production factors can be either produced within the district or purchased outside, because the spinning can be either carried out on a carder or a comber machine, and because dyeing can take place at different stages of the production process. However, all production chains must begin with a trader of finished products and end with a trader of raw materials. Figure 1 depicts the eleven possible production chains that are considered in this model.

The model depicts Pratese firms on a black display. Firms are represented by coloured squares according to the conventions illustrated in figure 2.

At the beginning of each year, the programme reads how many firms of each type there are in the district. If this number exceeds the number of firms that were in the district the previous year, the difference is dropped on the display at random locations. Conversely, if this number is less than the number of firms that were in the district the previous year, firms in excess are cancelled choosing at random among the firms on the display.

Firms numbers are available in 1:1, 1:2 and 1:10 scale. Since scaling affects the results of the model, 1:1 scaling should be used in order to derive sensible results. On the contrary, 1:10 scaling in order to get a visually clear picture of the formation of production chains. The advantages and drawbacks of 1:2 scaling lie in between.

Each single year is subdivided into steps. At each step, firms interact.

In order to obtain smooth results, we want the number of interactions to be approximately the same in each year. Since the number of firms and consequently the number of potential interactions varies each year, the number of steps cannot be the same every year. Thus, let us stipulate that the product of the number of steps and the number of firms must be a constant. Let this constant be $10,000,000$. Furthermore, let us speed up low-scale simulations by dividing the above number of steps by model scale. The ensuing formula for the number of steps to be performed during one year is:

$$steps\ number = \frac{1}{scale} \frac{10,000,000}{firms\ number}$$

At the beginning of each step, all firms except middlemen jump around the area. Traders of finished products, in particular, look for a middleman. As soon as they detect a middleman in their watching range, and if this middleman has a free side, they move aside it and place an order. Now the middleman looks around for suitable firms in order to build a production chain.

The middleman looks first of all for a firm that can be added to a trader of finished products, i.e. it looks for a finisher according to figure 1. As soon as it finds a finisher, it moves it close to the trader of finished products. Then the

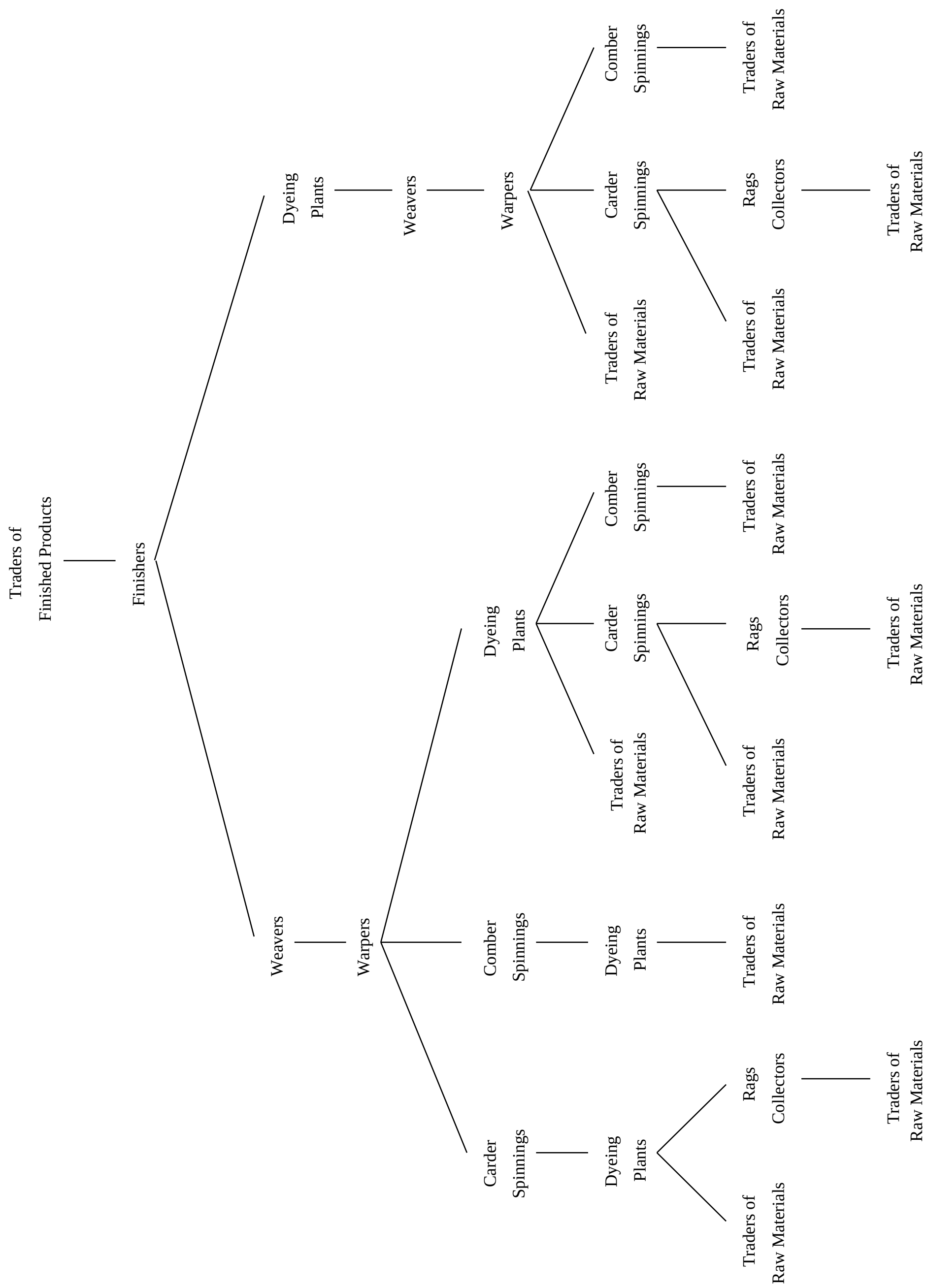

Figure 1: The eleven production chains that can be built by this model.

Figure 2: Colours and types of the firms depicted in figure 3.

middleman looks for a firm that can be added to a finisher, i.e. either a weaver or a dyeing plant, according to figure 1. And so on, until a trader of raw materials is found and the production chain is completed.

Since middlemen add firms to a production chain by displacing them, production chains appear on the screen as lines that depart from the four sides of the squares that represent middlemen. Thus, no more than four production chains can be attached to one middleman at a time. If there are obstacles along the way, production chains may take zig-zag shapes. Figure 3 illustrates a typical simulation step of the 1:10 model.

The choice of one out of the eleven possible production chains depends on which firms are nearest to a middleman. Implicitely, this model assumes that the empirically given number of firms subsumes all microeconomic variables that determine exchanges. It is a model that assumes economic equilibrium through firms reproduction and selection. It reconstructs the structure of production chains for any given economic equilibrium.

At the end of each step, all production chains are destroyed. All component firms are set free to jump around the area. However, if a trader of finished products remains close enough to the middleman, at the beginning of the next step it reconstructs another production chain starting from the same side of the same middleman. In this case, the observer of the simulation may have the impression that some production chains stay there for quite a long time.

However, the reconstructed chain is not necessarily the same as in the previous step. Firstly, because component firms may have jumped away at the end of the previous step. Secondly, because some firms (e.g. dyeing plants) can be placed at different points of a production chain. In this case, the observer of a simulation would see a production chain staying there with some of its coloured squares exchanging their places.

Once the model is set up, our task is that of identifying indicators that link the structure of production chains to flexibility of price and features of textile products. The next section derives four indicators of the structure of production chains and interprets their evolution from 1946 to 1993 in the light of the historical phases that Prato underwent.

5 The Indicators

Flexibility, be it price flexibility or features flexibility, is the competitive advantage of industrial districts versus single large firms. Thus, this is the first aspect that we

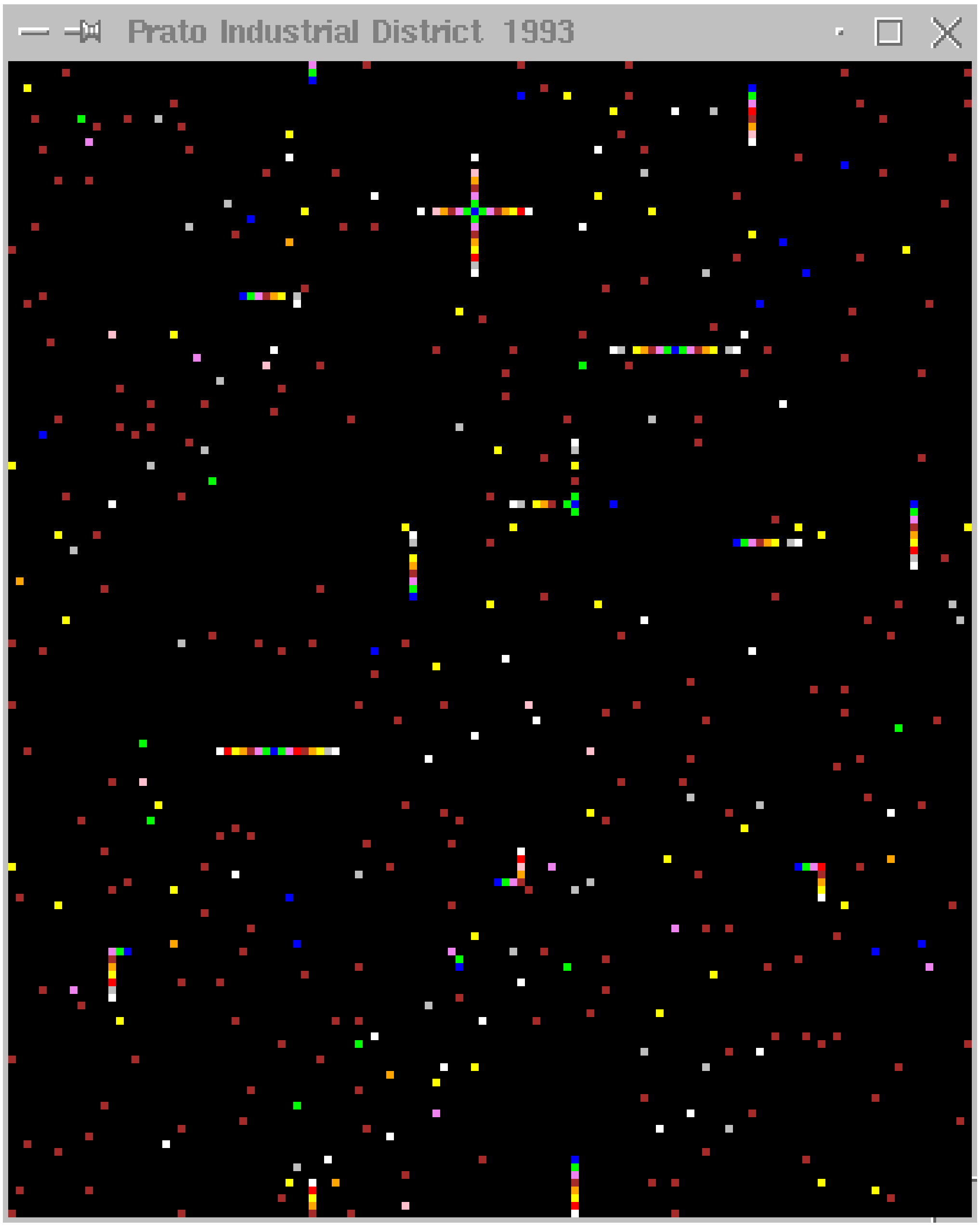

Figure 3: Prato industrial district. Holes denote production chains in the process of falling apart.

must attempt to capture.

Flexibility of a district does not depend on flexibility of its component firms, but rather on the fact that middlemen can choose among a wide variety of production chains. Variety of production chains, in its turn, depends both on the number of firms types and on the number of firms for each type.

Flexibility could be measured by means of an index of the variability of the production chains. The more variable production chains are, the more often middlemen change contracted firms and the more flexible the district is.

However, number of firms types and firms number set an upper bound to the flexibility that a district can attain. In particular, a limited number of firms types implies that with increasing volume of orders an increasing number of firms will be arranged into similar production chains at any given point in time.

This results in an increase of parallelism in information processing. That is, at each step there will be two or more information fluxes along identical production chains.

Although a certain degree of parallelism may contribute to the flexibility of the district, too high a parallelism indicates that the overall volume of orders is large enough for production to be organized more efficiently by larger firms.

The above considerations suggest to introduce the two following indicators in order to monitor the performance of the district. The first indicator is the variability of production chains, which is intended to measure the flexibility of the district. The second indicator measures the extent of parallelism of production chains, which reflects the scope for larger firms that would enjoy economies of scale.

Variability is computed as follows. At each step, the programme records which production chains have been built and to which side of which middleman they were attached. During each year, from the second step onwards the programme compares the chains that have been built at the end of the current step with the chains that had been built at the end of the previous step. Every time that a certain production chain is found attached to the same side of the same middleman as during the previous step, a variable `constancy` is incremented. Subsequently, a `degreeOfVariability` is defined as one minus the ratio of `constancy` to the number of chains that have been constructed during that step. A `summedDegreeOfVariability` sums the `degreeOfVariability` over a year. Finally, `averagedDegreeOfVariability` during one year is obtained by dividing `summedDegreeOfVariability` by the number of steps that have been made during that year.

Parallelism is computed as follows. At each step, the programme records which production chains have been built. At the end of each step, the programme checks whether a chain `X` appeared at least two times. If this occurred, a variable `chainXParallelism` is set equal to the number of chains `X` that have been built. Subsequently, these variables are averaged over all chains in order to yield a `degreeOfParallelism`. These values are added to one another to yield a variable `summedDegreeOfParallelism`. Finally, `averagedDegreeOfParallelism` during one year is obtained by dividing `summedDegreeOfParallelism` by the number of steps that have been made during that year.

Figure 4 depicts variability and parallelism calculated by the 1:1 model. Lower scale models cause the curves to shift to the right.

Variability increases continuously from the end of the 1950s, when the Prato industrial district began to expand, up to the end of the 1970s, when the crisis began. Parallelism, on the contrary, increases very slightly until mid 1970s. However, it rises very sharply during the late 1970s and reaches its maximum during the 1980s.

Thus, it appears that variability and parallelism are good at describing the birth of Prato as an industrial district, its expansion during the 1960s and 1970s, and the onset of the crisis with the 1980s. In fact, expansion took place when variability was increasing and parallelism was low. On the contrary, the crisis began when variability stopped increasing and parallelism had grown too much.

However, figure 4 is not informative as far as it regards the recovery of Prato during the 1990s. In fact, variability decreases very slightly during the 1980s as well as during the 1990s, while parallelism stays at one from the mid 1980s onwards. No change is visible passing from the 1980s to the 1990s.

The passage from price flexibility to features flexibility cannot be captured by the above curves because they do not distinguish among contributions by single components of production chains. Features flexibility is not attained uniformly along the production chain. Features flexibility relies on the ability of Pratese firms to propose a large number of patterns for their textiles, and most of this variety is attained during the last steps of the production process.

Finishers, that are at the very end of production chains, are good candidates to describe the rise of features flexibility. Both the number and the importance of finishing operations increased enormously during the 1990s.

On the contrary, price flexibility should be described by production phases that are at the beginning of the production process. However, picking firms like rags collectors or spinners poses a series of problems. One is that the importance of rags collectors decresed enormously since the 1980s, because Prato is making little use of regenerated wool. Similarly, since the 1980s Prato is doing less carder spinning and more comber spinning, so it is not clear which type of firm could

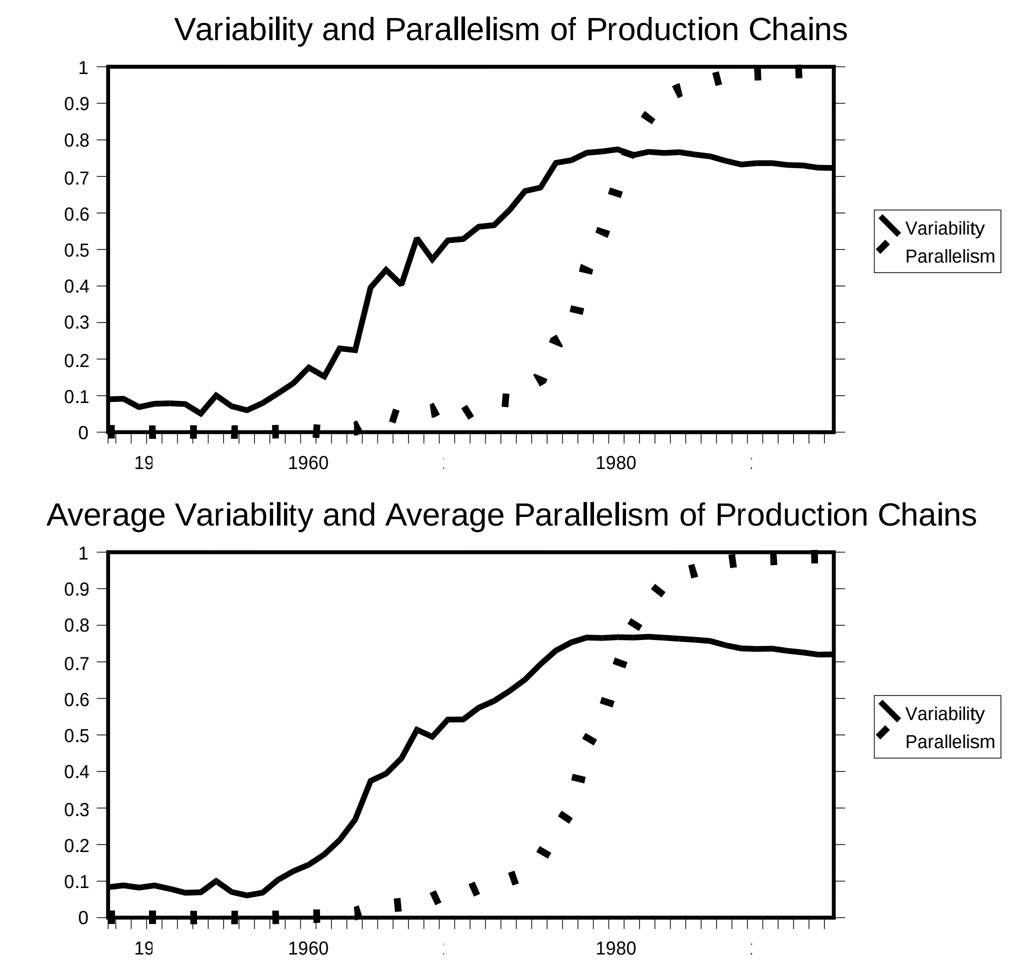

Figure 4: Variability and parallelism of production chains. Picture above shows variability and parallelism generated by one typical run of the model. Picture below show the average over ten runs, obtained feeding the random numbers generator with different seeds.

provide a reliable indicator of price flexibility. Finally, production phases that are at the beginning of the production process are those that have been transferred abroad to the largest extent, so any indicator relying on Prato-based firms would be biased.

Therefore, firms that are in the middle of the production process might be better candidates to provide an indicator of price flexibility. In particular, weaving is a typical job that provided Prato with price flexibility during the 1960s and 1970s. Weaving technology is such that looms can be purchased at a reasonable price and can be profitably operated by very small units, so the number of weavers is much higher than the number of any other firms in the district.

Thus, two other indicators have been introduced: finisher mobility and weaver mobility. These indicators refer to particular finishers or weavers included in the production chains built by a particular middleman at a particular side over time steps, regardless of chain types.

Finisher mobility and weaver mobility are computed as follows. Firstly, `finisherPersistence` and `weaverPersistence` are calculated. Persistence is the number of times that each particular finisher or weaver has been attached to the same side of the same middleman. It is calculated over blocks of one thousend chains built during one year, except for the last block of each year. Block values are averaged in order to obtain yearly values denoted `summedFinisherPersistence` and `summedWeaverPersistence`, respectively. Finally, `finisherMobility` and `weaverMobility` are calculated as one minus the ratio of persistence to the number of chains that have been built during that year.

The higher the mobility of a firm, the higher the flexibility it provides. Thus, if we assume that weavers mainly provide price flexibility while finishers mainly provide features flexibility, we can observe the evolution of the importance of these two factors. Figure 5 plots finishers mobility and weavers mobility calculated by the 1:1 model.

As the district was in its infancy, in the 1950s, finishers mobility and weavers mobility were both very low, generally constant and very close to one another. On the contrary, during the golden age from the beginning of the 1960s to the end of the 1970s finishers mobility and weavers mobility took constant values but weavers mobility was definitely higher than finishers mobility. From the beginning of the 1980s to mid 1990s, weavers mobility increased very slightly while finishers mobility increased at a fast pace. Consequently, at the beginning of the 1990s finishers mobility and weavers mobility were again very close to one another, but at higher absolute values.

Continuous increase of weavers mobility from the beginning of the 1980s sug-

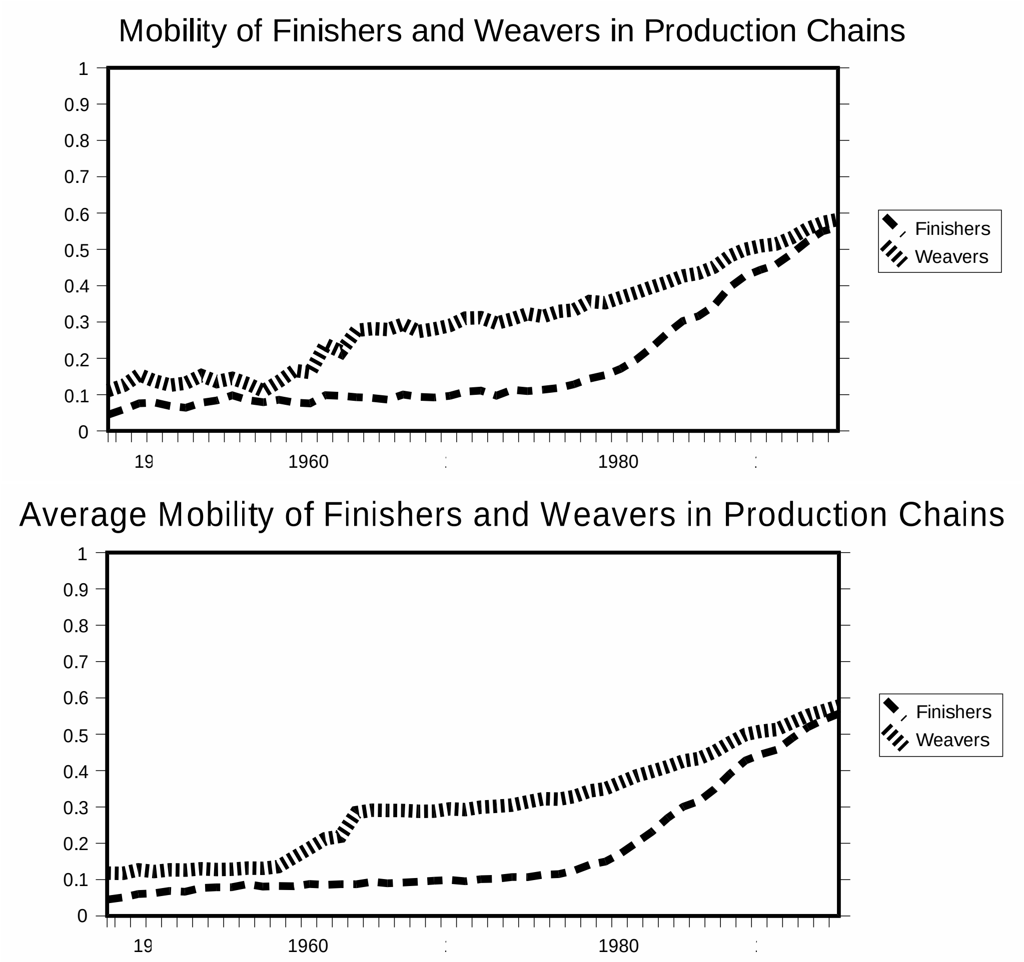

Figure 5: Mobility of finishers and weavers in production chains. Picture above shows mobilities generated by one typical run of the model. Picture below show the average over ten runs, obtained feeding the random numbers generator with different seeds.

gests that price flexibility was never completely abandoned, and actually increased since the onset of the crisis. The trend of finishers and weavers mobility suggests that the crisis was not overcome by exchanging price flexibility for features flexibility, but by adding features flexibility to a price flexibility that never disappeared. If this model is taken to be accurate enough to represent real phenomena, the persistence of price flexibility can only be explained by extensive exploitation of new immigrants.

The other interesting fact about the curves depicted in figure 5 is that they do not show any sharp divide between the crisis of the 1980s and the slow but steady recovery of the 1990s. On the contrary, features flexibility appears to have increased continuously from the onset of the crisis. A possible explanation is that a long time was needed in order for unprofitable, traditionally managed family firms to disappear from the market.

6 Conclusions

This research was initiated by a suggestion of an economist to a physicist, that industrial districts could possibly be studied as self-organizing systems. The original idea was to model an industrial district as a connectionist, self-organizing system. Thus, the idea underlying this research project was a variation of the ”social mind” metaphor, i.e. that individual firms are to an industrial district like ants are to the anthill like neurones are to the brain.

This idea had to be rejected in the course of the investigation because the Prato district appeared to have quite a complicated structure of its own, centered around the figure of middlemen. Furthermore, technological constraints pose certain limitations to the pairs of firms that can interact with one another.

These features make the Prato district very different from a cluster of neurones. In the case of a neural net, the neurons have so many degrees of freedom that they can easily establish complex structures of information fluxes. These structures give to the net certain capabilities, which no single neuron had planned or foreseen. On the contrary, our firms are complex and powerful enough to constrain the behaviour of the district.

Possibly, we are bumping into a kind of general principle. The above analysis suggests that the more intelligent the components, the less intelligent the whole. The human-hill might be less intelligent than the ant-hill.

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