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Individual Contacts, Collective Patterns – Prato 1975-97, a Story of Interactions

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INDIVIDUAL CONTACTS, COLLECTIVE PATTERNS

Prato 1975-97, a story of interactions

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Abstract

This article presents an agent-based model of Prato, an Italian textile district where thousands of small firms specialise into tiny phases of the whole production process. It is an empirical model at scale 1:1 that reconstructs the information flows between economic actors and connects them to structural properties of the district. It studies the evolution of Prato from 1975 to 1997.

1. Introduction

Industries are not scattered uniformly on earth surface. Rather, they concentrate at specific locations where they may make use of local natural resources and, most importantly, exploit and develop local knowledge. This is particularly evident when local industries are mainly composed by small and medium-sized firms, which establish a thick web of interactions that adds to the competitive advantage of all of them.

Marshall (1890) was first to call attention on the peculiar industrial structure that obtains when hundreds or thousands of small and very small firms coexist at a specific place. He had Sheffield's cutlery industry in mind, for which he coined the term *industrial district*. According to his formulation, an industrial district is not only a geographical cluster of firms that operate in the same industry, but also a place that develops a distinctive culture of making business, a complex combination of competition and collaboration on an intricate network of relationships which he called the *atmosphere* of a district.

Independently of Marshall and from a managerial perspective, Porter (1985) also stressed the importance of geographical proximity and networks of acquaintances for the competitive advantage of firms. With quite a similar meaning albeit a lower emphasis on the collaborative aspects of inter-firm relationships, Porter spoke of *industrial clusters*. Typically, contemporary discussions tend to use the term “cluster” when the focus is on geographical proximity and cost advantages, “district” when the focus is rather on sociological and communitarian aspects.

Becattini (1975) was first to recognise that the industrial development of Prato, a 200,000 town a few kilometers west of Florence (Italy), was following the path highlighted by Marshall. Similarly to other industrial sites, Prato developed a textile industry on thousands of small, sometimes minuscule family firms.

However, contrary to other textile districts in Europe and North America, Prato did not extinct once wages rose to levels that are much higher than in the rest of the world, and technologies made larger-scale production profitable. One reason is that, in spite of official data, Prato is a place of massive illegal immigration and widespread exploitation of a workforce that cannot fight for its rights (Harrison 1994; De Cecco 2000; Fioretti 2001). Still, one may sensibly ask why Pratese firms did not move all production abroad, as many European and North American counterparts did.

Although textile tradition in Prato dates back to the Middle Age, the formation of an industrial district is quite recent. Before World War II one may speak of a cluster of textile firms, typically, woollen mills of large size for large scale production of low-quality fabrics. However, it was the crisis following the war that marked a shift from a traditional, vertically integrated industrial structure to a flexible arrangements of a huge number of small firms specialised in a single production phase (Bisori 1951; Cioni 1997). In a situation of extreme poverty, with woollen mills shutting down or resizing their productive capacity, young members of large extended families devoted to agriculture started to integrate their income with some irregular work at the loom, for which they could eventually mobilise their whole family just as they used to do at harvest times. Another source of independent firms was provided directly by the large woollen mills, particularly during the 1949 crisis. Simply, workers were offered the option of either buying or renting looms or other machinery and to be contracted at demand peaks, or being fired.

The ensuing industrial district expanded through the 1960s and 1970s, becoming a sort of national phenomenon that was partly imitated by other industries throughout the country. However, at the beginning of the 1980s it was struck by a harsh crisis. Prato had been relying on competition among its thousands of small firms, which kept prices very low. However, low profits implied low innovation, a weakness that was enhanced by the fact that firms that would purchase modern machinery would suffer competition by crowds of despaired handworkers, ready to work however long in order to sell at whatever price (Bertini and Forlai 1989). Furthermore, transportation costs and waste of time associated with distributed production concurred to make the system weak with respect to larger firms located elsewhere (Bertini and Forlai 1989). Unanimously, experts predicted that the textile industry would move away from Prato.

Figure 1 illustrates statistics of the number of plants and number of workers in the textile industry from 1950 to 1995, province of Prato. The crisis of the 1980s is altogether evident, but it appears that since the 1990s the number of workers is more or less stable, while the number of plants continued to decrease albeit at a slightly slower pace than in the 1980s. Evidently, Prato had begun to recover.

PLEASE INSERT HERE FIGURE 1

Figure 1

Number of plants and number of workers in the textile industry, province of Prato (ISTAT 1951, 1961, 1971, 1981, 1991, 1996)

Contrary to the industrial structure that emerged during the 1950s and 1960s, a certain degree of industry concentration took place. However, according to a survey of 150 opinion leaders carried out in 1991-1992, statistics pointing to industry concentration mainly reflect closure of one-person firms, rather than increasing size of the surviving ones (Balestri and Toccafondi 1994).

In any case, industry concentration does not suffice to explain the recovery of the 1990s. In fact, the prediction was that the textile industry would move to low-wage countries, not that the textile district would transform itself but, ultimately, stay there. Although some production phases did move abroad, the bulk of firms is still in Prato.

According to a survey carried out among customers of Pratese firms in 1990, Prato's competitive advantage lies in its unique ability to provide anything a buyer may request, in a reasonable time, in lots of any size and with great creativity and taste (Balestri and Toccafondi 1991). What already in the 1970s had begun to change, what increased its pace in the 1980s and finally exploded in the 1990s, is product differentiation. Variety, and the capability to produce small lots of fabric, is the secret of Prato's competitive advantage today (Balestri 1990).

A distributed production system like this cannot be captured by an aggregate model. Interactions are the key to understand the shift from a competitive advantage based on low price in the 1970s to a competitive advantage based on variety in the 1990s. Availability of a large number of small firms specialised in a particular part of the productive process, yet each of them characterised by specific abilities and tastes, generates the potential for an enormous span of organizational arrangements and corresponding variations of the final product.

The late Hägerstrand pleaded for a research methodology where social and economic geographers would keep track of daily movements of people (e.g. house-work, during work, house-school, sporting activities etc.) and reconstruct the features of social organizations out of the structure of constraints that they pose to the way people spend their time (Hägerstrand 1970, 1982, 1985). This research program was terribly hard to implement in the 1970s and 1980s, but a variation of it, namely agent-based computer models, has become feasible in the meantime. The rest of this article presents one such model for the Prato textile district.

Subsequent sections are organized as follows. Section 2 explains the typical structure of interactions between Pratese firms, which is later reflected in the model. Section 3 illustrates the functioning of the model and the data on which it is based. Section 4 selects some indicators of the structure of interactions and illustrates the evolution of this structure from the mid 1970s to the end of the 1990s. Finally, Section 5 concludes.

2. The Structure of Interactions

During the 1970s and 1980s, scholarly accounts tended to depict industrial districts as egalitarian societies of small businesses that live in a world of harmony and cooperation. Although certain forms of inter-firm collaboration do exist and understandably attracted the attention of early investigators, this idealised picture is, alas, false (Amin and Robbins 1990; Amin and Thrift 1992).

The first myth to fall was that of an egalitarian society of small firms. A number of empirical investigations highlighted the importance of hierarchical structures within industrial districts, as well as the variety of these structures (Scott 1992; Gray, Golob, Markusen and Park 1998; Lazerson and Lorenzoni 1999; Rabellotti and Schmitz 1999).

In Prato, production is organized by a special class of firms, herein called the *middlemen* (Bertini and Forlai 1989). A middleman can either be one of the large woollen mills, or a much smaller firm composed – in the limit – by its owner, a storing facility and an answering machine.[1]

[1] In this case, Pratese jargon employs a local word: *impannatori*. It derives from *panno*, which means "cloth".

Contrary to most firms in Prato, middlemen have entrepreneurial spirit, they are able to make strategic plans and are acquainted with the fashion industry.

Whoever wants to buy in Prato, asks a middleman. If the order exceeds its productive capacity, a middleman calls several small firms in order to carry out specific production phases. Wares may not even need to pass physically through a middleman's workshop, but the sequencing of operations is up to him.

For a middleman, nothing is more crucial than that the identity of the final buyer remains secret to the firms that he contracts. Otherwise, these firms could possibly sell directly to the final buyer, eventually becoming middlemen themselves. Although informally, a hierarchy of firms does exist.

If a firm that has been contracted by a middleman is not able to fulfil the whole order with its productive capacity, it will contract another firm in its turn. Consequently, the contracted firm takes the role of a middleman with respect to the firm that it contracts in its turn. At least in principle, this structure of subcontracting can repeat itself over and over until the order placed by the first middleman found enough productive capacity.

The above observation is useful in order to clarify the issue of cooperation and collaboration in a district. Let us consider the oversimplified situation of a middleman M who alternatively contracts firm F1 or F2 illustrated in figure 2.

PLEASE INSERT HERE FIGURE 2

Figure 2
A middleman M may contract firm F1 (left) or F2 (right). If F1 is contracted and its productive capacity is not sufficient to fulfil the order, it contracts F2 in its turn. If F2 is contracted and its productive capacity is not sufficient to fulfil the order, it contracts F1 in its turn.

Suppose that M contracts F1, and that F1 has not enough productive capacity. Consequently, F1 may contract F2 in its turn, or build up its productive capacity. Likewise, suppose that M contracts F2 and that F1 has not enough productive capacity. F2 may either contract F1, or build up its productive capacity.

Since building up a productive capacity that is seldom used represents a cost, the best arrangement is that F1 contracts F2 and F2 contracts F1. In this way, capacity utilisation is smoothed against the vagaries of M. Let us call this the *cooperative* arrangement.

However, firms have an incentive not to cooperate. In fact, suppose that F1 has been contracted by M. F1 may think that, if it builds up its productive capacity, then F2 may go bankrupt because it does not get any job anymore. Let us say that F1 is deciding to *defect* from an implicit agreement.

If F1 builds up its productive capacity and F2 does not, then F2 is in trouble because it is not likely to be contracted by M anymore. But since F2 faces the same incentives as F1, the system is likely to end up with *both* F1 and F2 building up their productive capacity, which is a suboptimal arrangement with respect to contracting one another.

The situation described above is an instance of what Game Theory calls *prisoner's dilemma* (Von Neumann and Morgenstern 1947). It is paradigmatic of all situations where players have an incentive to be selfish, yet the best outcome can only be attained if they cooperate. Figure 3 illustrates a payoff matrix for firms F1 and F2. Payoff is represented by profits π.

PLEASE INSERT HERE FIGURE 3

Figure 3
A possible payoff matrix for the relationship between F1 and F2. Each firm is tempted to build up its productive capacity in order to increase its profits, but if both do that, they end up with lower profits than in the cooperative arrangement.

It is well known that the *prisoner's dilemma* reaches the cooperative solution if the game is repeated, i.e. if players have the possibility to learn that cooperation pays (Axelrod 1984). In Prato, all firms except middlemen are precisely in this situation, since each of them knows that it may be contracted by the firm that it contracts. Thus, cooperaction between contracted firms is actually observed.

Also, consider that very small family firms that passively depend on the orders of a larger one, and that often originated from workers of a large firm who had a choice between working on contract and being fired altogether, may be more akin to workers than to firms proper.[2] Legally, we may observe cooperating firms. *De facto*, they are very much akin to workers establishing a trade union or a mutual fund.

The relationship between a middleman M and a contracted firm, say F1, is entirely different. In fact, none of them has any incentive not to work with the other one, so the outcome is straightforward. In order to distinguish this situation from the previous one, we may call it *collaboration*. Figure 4 illustrates a possible payoff matrix for M and F1.

PLEASE INSERT HERE FIGURE 4

Figure 4
A possible payoff matrix for the relationship between M and F1. Since they cannot work in isolation, the collaboration/defect arrangements are nonexistent.

Summing it up, we may say that collaboration between middlemen and contracted firms is rather obvious, cooperation between contracted firms is less obvious yet economically feasible and culturally possible. It is the high levels of collaboration and cooperation that identify Prato as a prototypical industrial district.

3. Reconstructing Interactions

The philosophy of an agent-based model is that of reconstructing interactions between agents out of information on the behaviour of single agents. In our case, the idea is that if we can write a model that entails the typical behaviour of middlemen and contracted firms, we may reconstruct the flow of orders and the structure of production chains that are generated in the real district. To be more precise, we may construct a flow of orders and a structure of production chains that is akin to the one that actually obtained.

We want to construct an interpretative model of the recent history of Prato, particularly with regard to the shift from a competitive advantage based on low price to a competitive advantage based on products variety, the role of outsourcing from low-wage countries, and the relative proportions of different production processes in the district. To this aim, we need data on the number and size of firms that are specialised in each of the main production phase (e.g. warping, weaving etc.). Concretely, we need time series regarding the number and size of Pratese firms specialised in a particular production phase. The time span of these series should encompass the crisis of the 1980s and the recovery of the 1990s.

The model will proceed on a yearly basis. At the beginning of each year, the simulation programme will read data on the number and size of middlemen, warpers, weavers and other firms. Obeying the plausible rules of behaviour by which these agents will be endowed, they will simulate orders and production chains. If this is a plausible reconstruction of what actually happened, the changing structures of production chains should reflect the evolution of this industrial district.

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[2] These workers are called *contoterzisti*, which means "workers for a third party". Contracted workers, with a much less secure position than the employed ones.

Data at our disposal stem from *Istituto Nazionale per la Previdenza Sociale*, the State agency for social insurance (INPS 2001).[3] These data cover all firms that have at least one employee for which they must pay social benefits to INPS. From 1975 to 1997 we have records of all firms in the province of Prato, the number of their employees, their names and addresses, and a brief description of their activity. From the description of their activity and, to a lesser extent, from their names, we constructed a database of firms that are specialised in particular activities such as warping, weaving and so on. Selection criteria are explained in the appendix.

Our model aims at reconstructing flows of information, not flows of goods. These are related issues, yet not quite exactly the same.

We are interested in the orders that middlemen place to the firms that they contract. Thus, the model reconstructs phone calls or talks at the bar that give rise to production chains, not the material outcome of productive activity. This makes a difference when handling data.

In general, the number of orders that can be handled by a firm depends both on its size and the size of the lots that have been ordered. Since we have information on firms size but we do not have any information on lots size, we may make one of the following two hypotheses:

Hp.(1) Lots size is inversely proportional to firms size, i.e. smaller firms process smaller lots. Consequently, the size of firms does not influence the number of orders that they process.

Hp.(2) Lots size is independent of firms size. Consequently, larger firms process larger orders.

Clearly, the above hypotheses are extremes. Reality is likely to lie in between. Hypothesis (1) is likely to apply to small firms, which are unfortunately underrepresented in our database because it does not include one-person firms. It may apply quite well to middlemen as well, since the size of the orders that they place mainly depends on their commercial acquaintances. Thus, we may add a third hypothesis to the previous ones:

Hp.(3) Middlemen follow hypothesis (1). All other firms follow hypothesis (2).

Hypotheses (2) and (3) present a further problem, namely, that it is not obvious to what extent the size of firms, measured by the number of employees, affects the number of orders that they process. Lacking information on the production functions, we shall implement hypotheses (2) and (3) by assuming that the number of employees is directly proportional to the number of orders, i.e. that a firm with two employees processes twice as many orders than a firm with one employee.

If hypotheses (2) or (3) are accepted, some firms necessarily process a larger number of orders per unit time than others do. Consequently, in order to keep the model at a tractable level we shall define equivalent production units of one employee as the basic interacting agents of our model. In other words, if hypothesis (1) is accepted the number of interacting agents will coincide with the number of firms. On the contrary, if hypothesis (2) is accepted the number of interacting agents will coincide with the number of employees. Finally, if hypothesis (3) is accepted the number of interacting agents will coincide with the number of middlemen plus the number of employees in contracted firms.

Under hypothesis (1), the number of agents ranges between 1,556 in 1975 and 2,622 in 1985. Under hypothesis (2), the number of agents ranges between 19,246 in 1993 and 33,039 in 1980. Finally, under hypothesis (3) the number of agents ranges between 15,821 in 1993 and 24,005 in 1980.

Agents fall into types that have been selected in order to highlight the features of the production processes enacted in Prato. Traditionally, Prato used to produce low-quality, low-price textiles out of regenerated wool. Regenerated wool is obtained from used clothes and woollen rags of almost any sort, after a series of chemical and mechanical processes that yield less resistant, rougher fabrics than virgin wool. Of the two spinning methods – carded spinning and combed spinning – only the first can be used with regenerated wool. However, identifying carded fabrics with lower-quality fabrics would be a mistake, since quality rather depends on raw materials and processing details. Today, wool regeneration almost disappeared from Prato, average quality is

[3] Data have been kindly provided by Prof. Giuseppe Tattara of the University of Venice, who accessed them in the framework of MIUR 2001.20011134473.

much higher than it used to be, but still, for historical reasons, most Pratese firms are focused on carded fabrics.

Figure 5 illustrates a general scheme of the production process to be found in Prato (Avigdor 1961). Wool (either virgin or regenerated) must be spun (either carded or combed), warped and then woven. Dyeing can either take place before spinning, or between spinning and warping, or after weaving. Finally, fabrics receive a final touch with finishing operations. Since technical innovations either concern machinery or details that at this level of generality do not show up, we can safely assume that this scheme did not change.

PLEASE INSERT HERE FIGURE 5

Figure 5
A scheme of the production processes to be found in Prato, rough enough to be considered constant over time. Dyeing can either take place before spinning, or before warping, or just before finishing operations.

The scheme of figure 5 suggests that the model should be able to highlight the role of regenerated wool, that it is important that both carded and combed spinning are represented and that dyeing adds variety to the possible production chains if warping and finishing are also included. Furthermore, a very good reason for including finishing operations will be explained in the next section. Traders of raw materials and traders of finished products play the important role of interfaces with the rest of the world. Finally, middlemen play the crucial role of organizers of production.

Ultimately, ten types of agents have been considered: 1) Traders of Raw Materials; 2) Rags Collectors; 3) Carded Spinnings; 4) Combed Spinnings; 5) Warpers; 6) Weavers; 7) Dyeing Plants; 8) Finishers; 9) Trader of Finished Products; 10) Middlemen. Given these types of agents, technological constraints restrict the set of possibilities to the 11 production chains illustrated in figure 6.

PLEASE INSERT HERE FIGURE 6

Figure 6
The eleven production chains that can be constructed with the ten given types of firms. Abbreviations are as follows: TRM = Trader Raw Materials; RC = Rags Collector; CaS = Carded Spinning; CoS = Combed Spinning; Wa = Warper; We = Weaver; DP = Dyeing Plant; F = Finisher; TFP = Trader Finished Products. Middlemen are not really part of production chains, but rather organise them.

Production chains may vary from one another because some production factors can be either produced within the district or purchased outside, because spinning can be either carded or combed, and because dyeing can take place at different production stages. Nonetheless, all production chains must begin with a trader of raw materials and end with a trader of finished products.

Figure 7 illustrates production chains that vary from one another because of the sequencing of operations, because they make use of carded or combed spinning, and because intermediate products are purchased outside the district. In this latter case, production chains are shorter.

PLEASE INSERT HERE FIGURE 7

Figure 7
Four production chains. Chain A consists of buying wool, combed spinning, dyeing, warping, weaving, finishing and selling fabrics. Chain B differs from chain A because it makes use of carded spinning, rather than combed spinning. Chain C differs from chain B only because dyeing takes place at a later stage. Finally, chain D differs from chain C because yarn is purchased outside the district.

Agents move in a space that represents acquaintance proximity. When a new agent is created – at the first simulation year, or at the beginning of a subsequent year if the number of agents increased – it is dropped on a location chosen according to a uniform probability distribution.

At each simulation step, all agents except middlemen make a random move in the area. In particular, traders of finished products look for a middleman. As soon as they detect a middleman in their watching range, and after checking that at least one of its four sides is free, they move there and place an order. At this point, the middleman looks around for suitable firms in order to build a production chain that fulfils the technological constraints illustrated in figure 5.

In order to arrange a production chain, a middleman looks first of all for an agent that can be added to a trader of finished products. According to figure 6, this must be a finisher. As soon as the middleman finds a finisher, he attaches it to the trader of finished products. Then the middleman looks for an agent that can be added to the finisher, that according to figure 6 can either be a weaver or a dyeing plant. And so on, until a trader of raw materials is found and the production chain has been completed.

Thus, selection of one out of the eleven possible production chains depends on which agents are nearest to the middleman. Implicitly, this model assumes that the empirically given number of agents subsumes all microeconomic variables that determine exchanges. In other words, it implicitly assumes economic equilibrium through firms reproduction and selection and reconstructs the structure of information flows for any given equilibrium state.

At the end of each step, all production chains are destroyed and their components are set free. However, if the trader of finished products remains close enough to the middleman, the next step it will prompt the construction of a production chain attached at the same side of the same middleman.

However, the reconstructed chain is not necessarily identical with the previous one. Firstly, because agents may have changed even if their type did not. Secondly, because dyeing plants can be placed at different points of a production chain.

The code has been written in objective C on the Swarm-2.2 platform. It is freely available at `http://econwpa.wustl.edu/eprints/prog/papers/0210/0210001.abs` and can be distributed under the GNU public license. Swarm is available at `http://www.swarm.org`.

4. Analysing Interactions

Preliminary trials highlighted that by scaling down the number of agents the model did not yield sensible results, so only a 1:1 reproduction of the Prato industrial district has been considered. This is important, because it suggests that empirical agent-based models absolutely must reproduce the ground level of interactions.

The model has three parameters, namely the variance of the normal distribution by which the traders of finished products move at each step, the size of the area where they look for a middleman, and the size of the world where agents are placed. With hypothesis (1) there are 2,000 to 3,000 agents each year; with hypotheses (2) and (3) there are 20,000 to 30,000. In the first case, a parameters choice that yields sensible results is a variance of 10.0, a watching area of 100 and a world of 300,000 pixels. In the second and third case, the world size has been increased to 3,000,000 pixels.

In order to check the sensitivity of the model with respect to these parameters, six series of five simulations have been run, each series decreasing or increasing a parameter by 10%. In other words, in the case of hypothesis (1) the model was run five times with variance 9.0, five times with variance 11.0, five times with watching area 90, five times with watching area 110, five times in a world of 270,000 pixels and five times in a world of 330,000 pixels. In the case of hypotheses (2) and (3), same as before as far as it concerns the variance and the watching area but 2,700,000 and 3,300,000 pixels as far as it concerns the world size.

The effect of parameters variation was measured on the relative proportions of the eleven different production chains that the model is able to reconstruct. Table 1 illustrates the mean across 23 simulation years and 11 production chains of the square errors of the mean of five simulations with altered parameters with respect to the mean of five simulations with base parameters values. The last row illustrates the square error of the mean of five simulations with base parameter values with respect to the mean of other five simulations with base parameter values. Since the values in the first six rows do not indicate tremendous differences from the values in the last one, we can conclude that with the above choice of parameters the model finds itself in a very stable region, where results only depend on input data.

Table 1

	Hypothesis 1	**Hypothesis 2**	**Hypothesis 3**
Variance – 10%	0.003 %	0.003 %	0.018 %
Variance + 10%	0.002 %	0.003 %	0.019 %
Watching Area – 10%	0.006 %	0.004 %	0.019 %
Watching Area + 10%	0.008 %	0.004 %	0.016 %
World Size – 10%	0.027 %	0.007 %	0.023 %
World Size + 10%	0.010 %	0.010 %	0.016 %
Base Parameter Values	0.002 %	0.003 %	0.015 %

The output of this model are the production chains that it reconstructs. These production chains can be of eleven different types, so the properties of their distribution are not immediate to grasp. However, they become clear if production chains are grouped according to the features that one wants to highlight.

A first criterion is that of grouping production chains according to the stage where traders of raw materials provide input to production. According to the scheme illustrated in figure 6, traders of raw materials may either deliver used-up cloths if they supply rags collectors, or wool if they supply spinners, or yarn if they supply later stages of the production chain. Thus, we can group production chains according to the raw material from which they start: rags, wool, or yarn.

Fabrics produced out of regenerated wool are of lower quality than fabrics produced out of virgin wool, so the relative share of production chains starting from rags gives us a clue about the evolution of the quality of finished goods. Early production phases are the simplest ones, and consequently those that are most likely to be moved to low-wage countries. Thus, the relative share of production chains starting from yarn gives us a clue of the extent to which delocalization has taken place.

It is well known that regenerated wool, once the main source of Pratese fabrics, is no longer employed. It is also known that delocalization did take place to some degree, but it is difficult to say to what extent (Balestri and Toccafondi 1995).

Figure 8 illustrates the outcome of the model in terms of the relative share of the number of chains that starts from rags, wool or yarn, respectively. Dotted separation lines illustrate the outcome of the model under hypothesis (1), dashed-dotted separation lines illustrate the outcome of the model under hypothesis (2), full separation lines illustrate the outcome of the model under hypothesis (3).

PLEASE INSERT HERE FIGURE 8

Figure 8
Shares of production chains starting from rags, wool and yarn, respectively. Lines separate three regions representing the relative shares of production chains. Dotted separation lines obtain under hypothesis (1), dashed-dotted lines obtain under hypothesis (2), full lines obtain under hypothesis (3).

It is clear that data are critical for a good outcome of the model. Only under hypotheses (1) and (3) the model reproduces the fall in usage of rags that is known to have taken place. Furthermore, only under hypothesis (3) the model shows an increase of the use of yarn produced outside the district, which probably did take place. Nevertheless, reliable data would allow to reconstruct phenomena about which, at present, only rumours are known.

A second criterion for grouping production chains is that of distinguishing carded spinning from combed spinning. Of these two spinning techniques, only carded spinning can be applied to regenerated wool. For this reason, Prato traditionally focused on carded spinning. Today combed spinning is equally viable, and it is interesting to see whether it has been adopted. It is worth to stress that carded wool looks different from combed wool, but that carded wool is not necessarily of lower quality than combed wool. It all depends on raw materials.

Figure 9 illustrates the outcome of the model in terms of the relative share of the number of production chains that use carded or combed spinning, respectively. Dotted separation lines illustrate the outcome of the model under hypothesis (1), dashed-dotted separation lines illustrate the outcome of the model under hypothesis (2), full separation lines illustrate the outcome of the model under hypothesis (3).

PLEASE INSERT HERE FIGURE 9

Figure 9
Shares of production chains using carded and combed spinning, respectively. Lines separate two regions representing the relative shares of production chains. Dotted separation lines obtain under hypothesis (1), dashed-dotted lines obtain under hypothesis (2), full lines obtain under hypothesis (3).

Independently of the hypothesis under which data have been extracted, it appears that the share of combed spinning did not increase at all; indeed, it eventually shrank. Apparently, Prato continued on the track that was once set by a technological constraint even after this constraint disappeared.

Although production chains are the immediate outcome of the model, one may sensibly ask whether it is possible to reconstruct the historical shift from a competitive advantage based on price to one based on fabrics variety that took place after the crisis of the 1980s. This is namely the most important development in the history of this industrial district, the one which allows it to exist in spite of fierce competition from low-wage countries.

A hint for defining a suitable indicator comes from the observation that variety is mainly created during the last phases of production, which increased enormously its scope during the 1990s (Aiazzi, Baussola, Corsini, Ganugi and Langianni 1997). Particularly, finishing operations have become able to add a number of features to the final product.

Certainly, each finisher increased the spectrum of processes that it is able to carry out. However, potential variety was magnified by the fact that each middleman can resort to any finisher so the whole spectrum of finishing operations that are carried out in the district are accessible to everybody. Thus, an indicator of the mobility of finishers across middlemen might signal the extent to which the district is relying on products variety.

This mechanism is akin to the one on which Prato based its competitive advantage in the 1960s and 1970s, namely, that each middleman could resort to a number of firms to contract and hence obtain low prices. Thus, mobility of firms performing traditional operations might be a good indicator of the extent to which the district is relying on low prices. Rags collectors may not do because regenerated wool is little used in Prato nowadays. Spinners would pose the problem of choosing between carded and combed spinning. On the contrary, weavers are an ideal candidate because, traditionally, weaving can be performed with simple machinery by the members of one family so this is the place where price competition is likely to be harder.

Let us define an index of mobility of weavers and finishers. Firstly, let us calculate `persistence`. This is the number of times that each particular weaver (finisher) has been attached to the same side of the same middleman. The program calculates it over blocks of one thousand chains, except for the last block of each year. Block values are averaged in order to obtain yearly values. Finally, `mobility` is calculated as one minus the ratio of persistence to the number of chains that have been built in a year.

Figure 10 illustrates mobility of weavers and finishers on the data extracted according to hypothesis (3). At the beginning of the 1990s we can observe a sharp transition from a regime where weavers mobility was higher than finishers mobility, to the reverse. The new regime might well represent the shift from a competitive advantage based on price to a competitive advantage based on products variety that characterised the recovery of the 1990s.

PLEASE INSERT HERE FIGURE 10

Figure 10
Mobility of weavers (thin line) and finishers (thick line). Data have been extracted under hypothesis (3).

A previous application of the same model to a different set of data yielded qualitatively similar results (Fioretti 2001).[4] In that case, data consisted of the number of firms in Prato from 1946 to 1993 regardless of their size (Lazzeretti and Storai 1999). Thus, hypothesis (1) was made. However, a big difference with present data is that even minuscule firms with no employee were considered, so for instance there was a huge number of weavers that are absent in these data.

Unfortunately, by making hypotheses (1) or (2) the interesting phenomenon depicted in figure 10 disappears. In both cases, weavers mobility and finishers mobility stay all the time very close to each other.

This circumstance makes clear that availability of reliable data is crucial for the reliability of an agent-based model. The problem is that, at present, data are not collected having in mind this sort of applications. Agent-based models require data regarding the relationships between well-defined independent decision units, whereas statistical institutes collect data regarding the status of firms and other agents as if they were isolated from one another.

In this study an attempt was made to make use of very general technological constraints in order to reconstruct interactions and to derive the number of decision-making units from data that had been collected for entirely different purposes. Three hypotheses could reasonably be made, of which hypotheses (1) and (2) were sorts of extremes and (3) was somehow in-between. Consequently, it is not surprising that the data extracted according to hypothesis (3) yielded the

[4] In that study, two other indicators were defined: *variability* and *parallelism*. Their performance with the present dataset is consistent with the previous publication, but in the present context they have been omitted because they are only meaningful if data earlier than 1975 are available.

most plausible results. However, dedicated data would be needed in order to use agent-based models for predictive purposes.

Pleading for novel ways of collecting data may not be as hopeless as it seems at first sight. For instance GDP and the other macroeconomic magnitudes did not exist before Keynes constructed a theory that needed them. Thus, if agent-based modelling will continue to diffuse, appropriate data will be collected.

5. Conclusions

The purpose of this paper was that of illustrating the potentialities of agent-based modelling for regional science on a concrete example, namely one where little quantitative analysis has been done. Essentially, agent-based models are appropriate when macroscopic outcomes depend on the structure of microscopic interactions. In this case, aggregate models fail to grasp the causes of macroscopic events. On the contrary, agent-based models work at the micro and macro levels at the same time, generating macroscopic trends out of microscopic actions – the so-called *butterfly effect*.

Until now, most agent-based models have been developed to be toy models. Nonetheless, a time has come when this technique should accepts confrontation with reality.

As it should have become clear, the main difficulty is the lack of appropriate data. The model that has been presented herein does its best to make use of data that had been collected for entirely different purposes, but its results cannot be taken as definitive achievements. Rather, it should be considered as an intermediate step between methodological toy-models and predictive empirical agent-based models.

Acknowledgements

This study is at odds with prevailing literature on Prato, particularly as far as it regards the presence of a structure of interactions centred around middlemen but also as far as it regards the reality of exploitation of clandestine immigrates. As such, it raised harsh criticisms, enthusiastic comments and surprised remarks. Since all of them concurred to improve my paper, I am equally grateful to Peter Allen, Tito Arecchi, Alberto Baccini, Harald Bathelt, Marco Bellandi, Fiorenza Belussi, Lucio Biggiero, Gabi Dei Ottati, Paolo Giaccaria, Robert Hassink, David Lane, Luciana Lazzeretti, Mauro Lombardi, Peter Maskell, Bart Nooteboom, Päivi Oinas, Antonio Politi, Roberto Serra, Fabio Sforzi, Flaminio Squazzoni, Dimitri Storai, Deborah Tappi, Michael Taylor, Erik Vatne, Alessandro Vercelli, Bauke Visser, Sieglinde Walter and Jici Wang.

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Finally, it is hard to say how much I feel indebted to the continuous help, assistance and, most importantly, encouragement and esteem by Pietro Terna, who sacrificed the honours of congress limelights in order to defend an uncomfortable paper.

Appendix

This appendix explains the criteria by which firms have been selected by examining their name and the description of their activity. Not all textile firms have been selected, but only those that could be identified as carrying out one of the production phases described by the model. In order to include all words with the relevant root, only parts of keywords have been included in the search. In most cases, computer search had to be integrated by manual refining.

- **Carded Spinning**. Search for entries that entail FILATUR [spinning], or PROD [production] and FILAT [spun fabrics], excluding those that entail LANIF [woollen mill] or COMM [commerce], VENDIT [selling] or PETT [combed spinning]. Subsequent manual exclusion of spinners that also declare LOCAZIONE [tenancy], PERSONALE DIR [managing personnel] or COPERTIFICIO [blanket production] without FILATURA [spinning].
- **Combed Spinning**. Search for entries that entail FIL [spinning] and PETT [combed] but not TESSITURA [weaving]. Manual exclusion of a firm that declared to produce MOQUETTE [moquette].
- **Dyeing Plant**. Search for entries that entail TINTORIA [dyeing plant]. Manual exclusion of entries that also entail LAVANDERIA [laundry].
- **Finisher**. Search for entries that entail FINISS [finishing], RIFIN [refinishing], NOBIL [ennoble] but not PELLICC [fur], GUANTI [gloves], CONFEZION [clothes], ABBIGLIAMENTO [clothes] and METAL [metallic]. Manual exclusion of refinishing of synthetic furs.
- **Middleman**. Search for entries that entail IMPANN [middleman] and LANIF [woollen mill] but not C/T [for a third party], S.P.A. [large firm]. Search for TESS [textiles] but not C/T [for a third party], FINANZ [financial] and COMM [commerce]. Manual exclusion of entries that suggest activities for third parties: TESSITURA [weaving], ORDITURA [warping], RIFINIZIONE [refinishing], FINISSAGGIO [finishing], CONTROLLO [check], RAMMENDO [mending], TINTORIA [dyeing], PELLICCE [fur] and FIBRE SINTETICHE [synthetic fibres].
- **Rags Collector**. Search for entries that entail STRACCI [rags] or CASCAMI [fabric waste] but not LAVORAZ [processing], TRASFORMAZ [transformation], SFILACCIATURA [fraying out], STRACCIATURA [tearing], CARBONIZZ [carbonization], CARTA [paper]. Subsequent exclusion of LAV [washing].
- **Trader Finished Products**. Search for entries that entail COMM [commerce] or ESPORT [export] or RAPPRESENT [commercial agent] or INGROSSO [wholesale], and TESSILI [textile] and PROD [products], or TESSUTI [textiles] or STOFFE [material].
- **Trader Raw Materials**. Search for entries that entail COMM [commerce], IMPORT [import], RAPPRESENT [commercial agent], INGROSSO [wholesale] and LANA [wool] or FILATI [spinned materials] or MAT and PRIME and TESS [textile raw materials]. Manual exclusion of entries connected with the wool guild.
- **Warper**. Search for entries that entail ORDIT [warper].
- **Weaver**. Search for TESSITURA [weaving], TESSUTI [textiles], ARTICOLI TESSILI [textile articles], PRODOTTI TESSILI [textile products] and INDUSTRIA TESSILE [textile firm] but not S.P.A. [large firm], GRUPPO [group] or GROUP [group] unless they explicitly declare to work C/T [for a third party]. Exclusion of entries that entail also FILATURA [spinning], VENDITA [selling], COMM [commerce], FINANZIARIA [financial], MODA [fashion],

ABBIGLIAMENTO [clothes], CONFEZIONI [clothes], FIBRE SINTETICHE [synthetic fibres] and generic sentences such as LAVORAZIONE TESSUTI [textiles processing].

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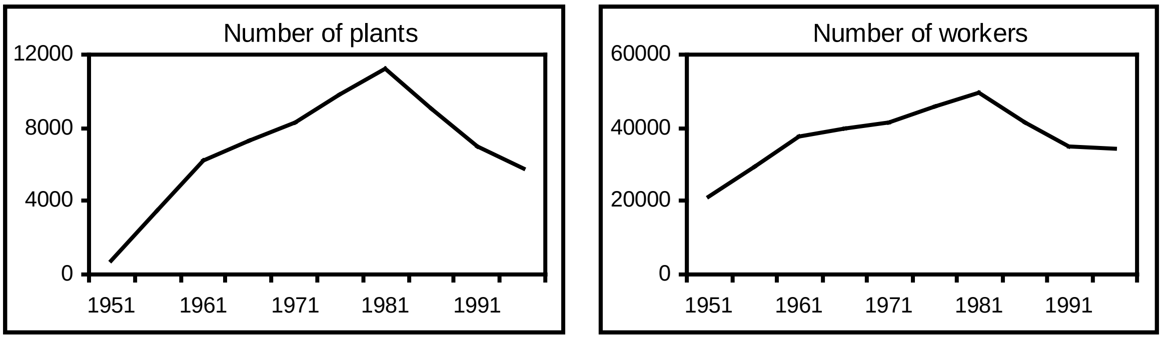


FIGURE 1

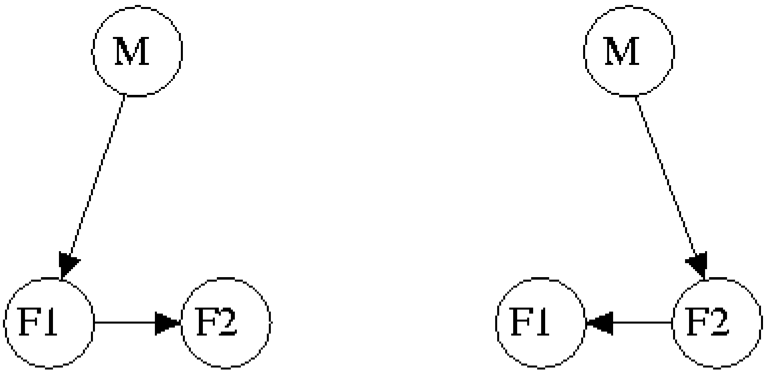


FIGURE 2

		F2	
		Cooperate	Defect
F1	Cooperate	π (F1) = 10 π (F2) = 10	π (F1) = 0 π (F2) = 15
	Defect	π (F1) = 15 π (F2) = 0	π (F1) = 1 π (F2) = 1

FIGURE 3

		M	
		Collaborate	Defect
F1	Collaborate	π (F1) = 10 π (F2) = 10	
	Defect		π (F1) = 0 π (F2) = 0

FIGURE 4

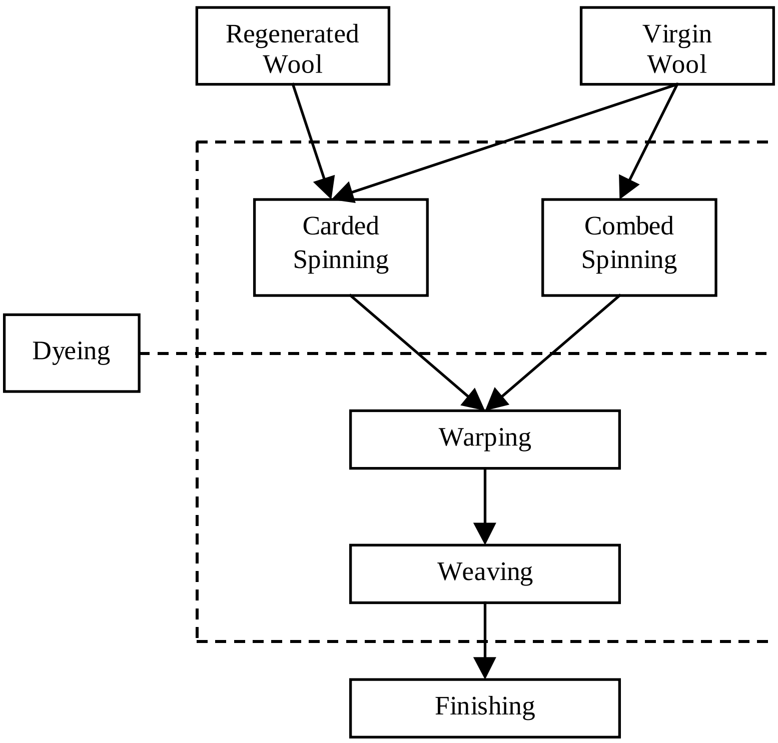

Regenerated Wool
Virgin Wool
Carded Spinning
Combed Spinning
Dyeing
Warping
Weaving
Finishing

FIGURE 5

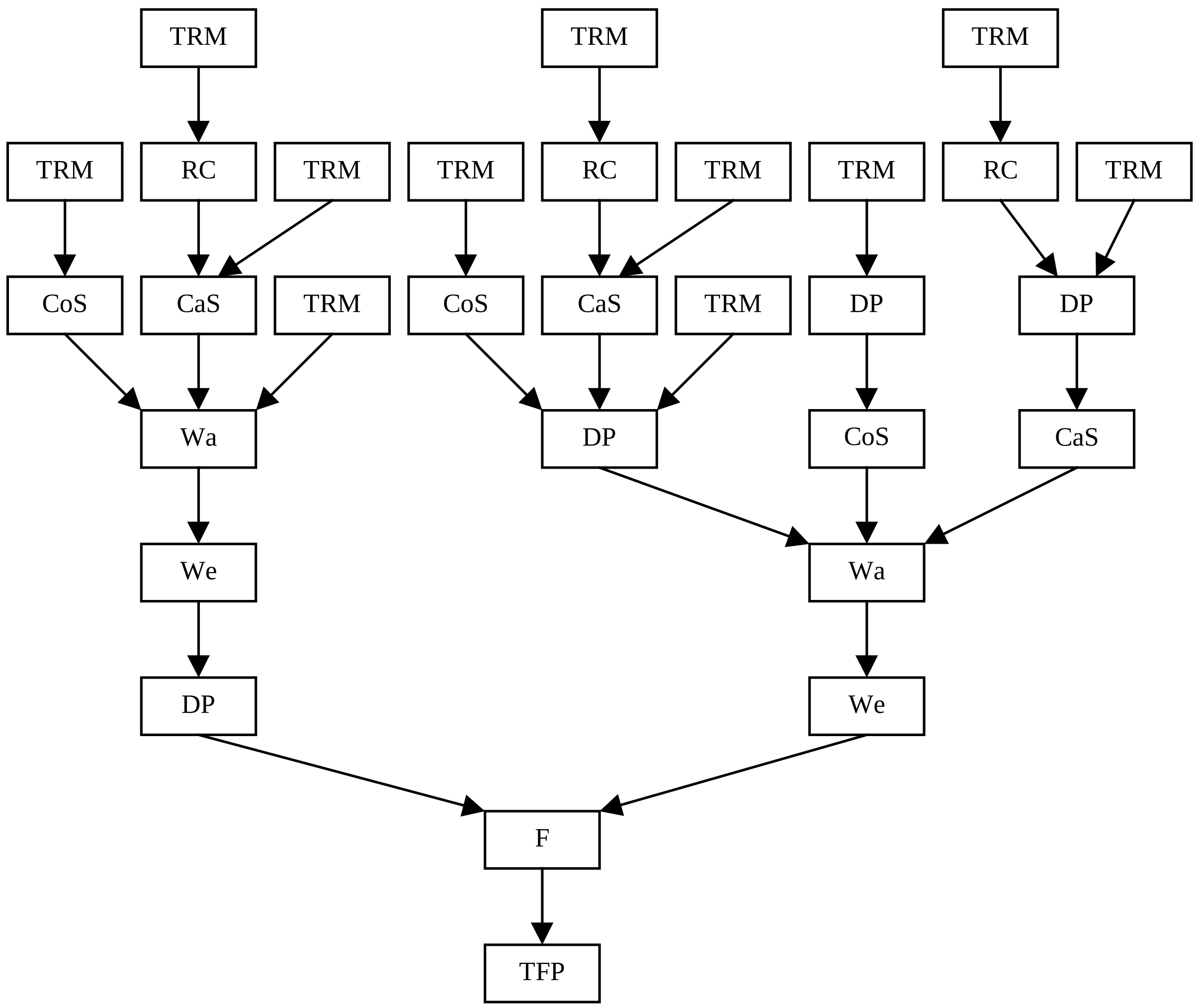
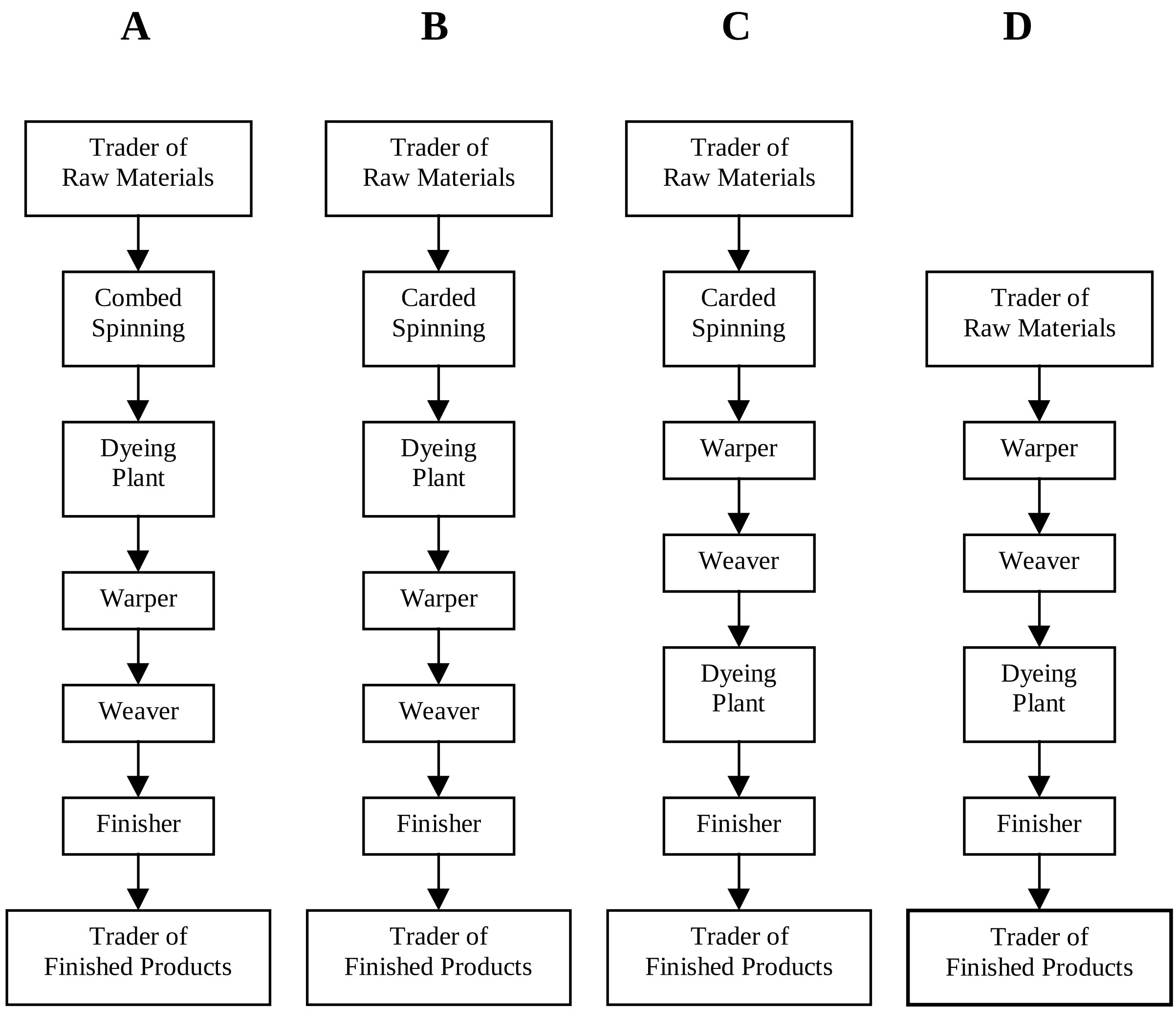

TRM
TRM
TRM
TRM
RC
TRM
TRM
RC
TRM
TRM
RC
TRM
CoS
CaS
TRM
CoS
CaS
TRM
DP
DP
Wa
DP
CoS
CaS
We
Wa
DP
We
F
TFP

FIGURE 6


A
B
C
D
Trader of
Raw Materials
Combed
Spinning
Dyeing
Plant
Warper
Weaver
Finisher
Trader of
Finished Products
Trader of
Raw Materials
Carded
Spinning
Dyeing
Plant
Warper
Weaver
Finisher
Trader of
Finished Products
Trader of
Raw Materials
Carded
Spinning
Warper
Weaver
Dyeing
Plant
Finisher
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Finished Products
Trader of
Raw Materials
Warper
Weaver
Dyeing
Plant
Finisher
Trader of
Finished Products

FIGURE 7

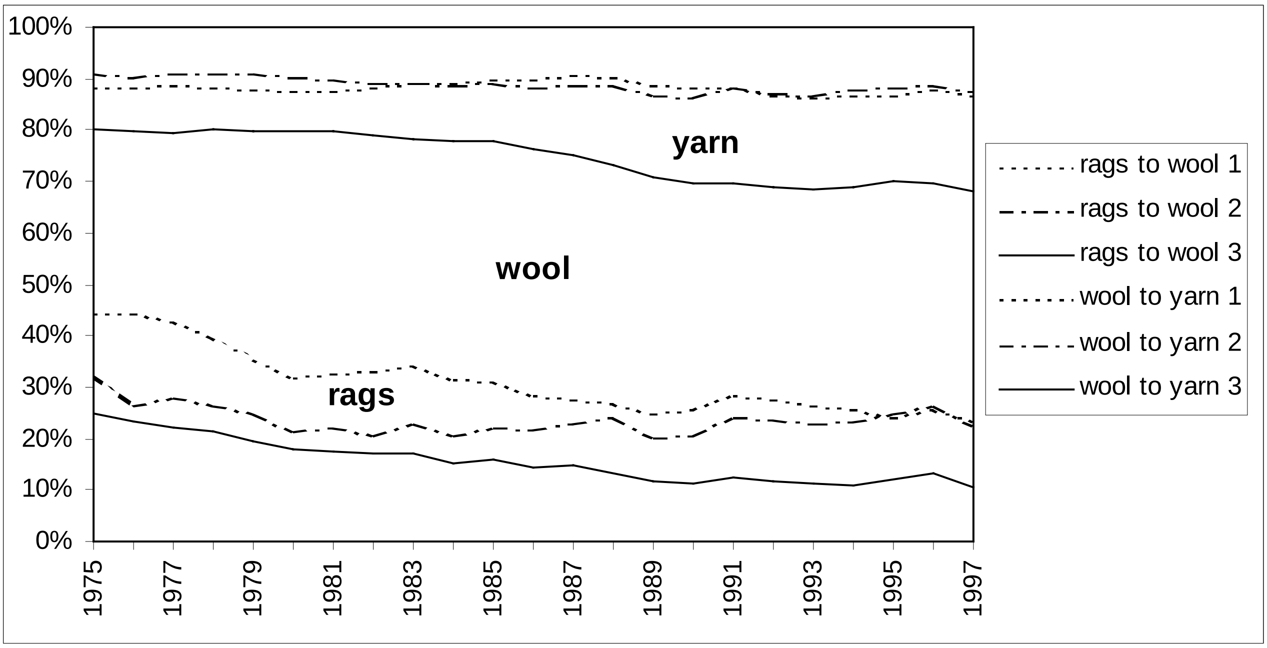

FIGURE 8

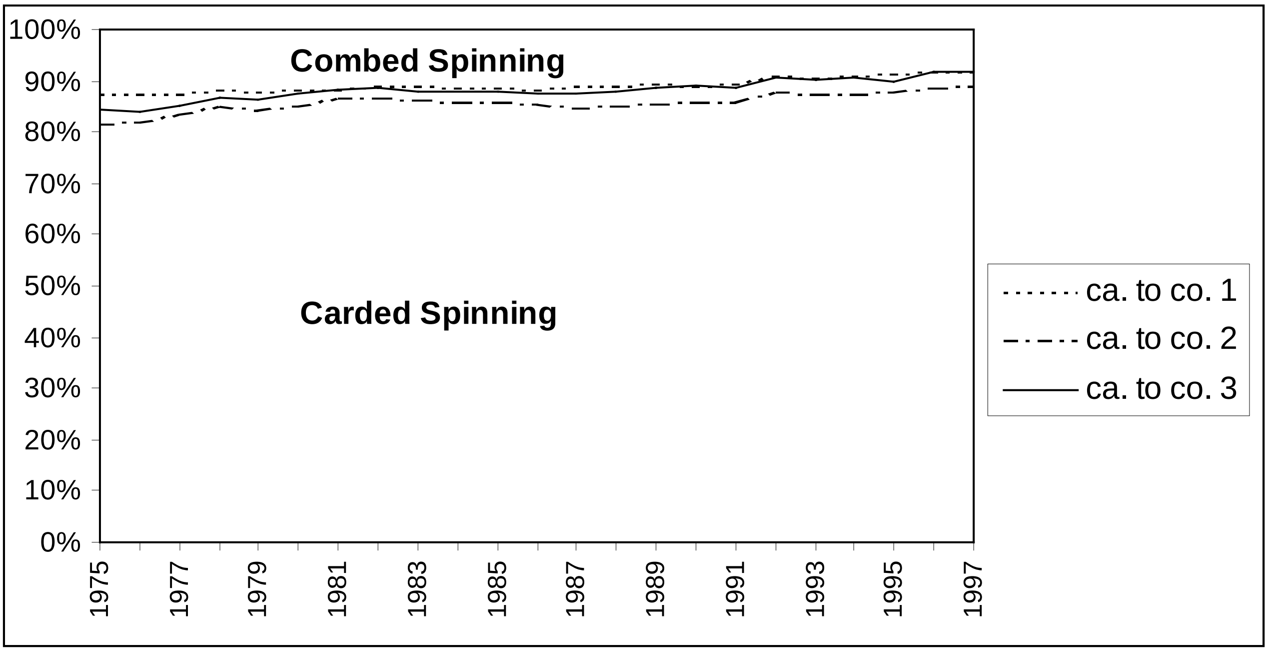

FIGURE 9

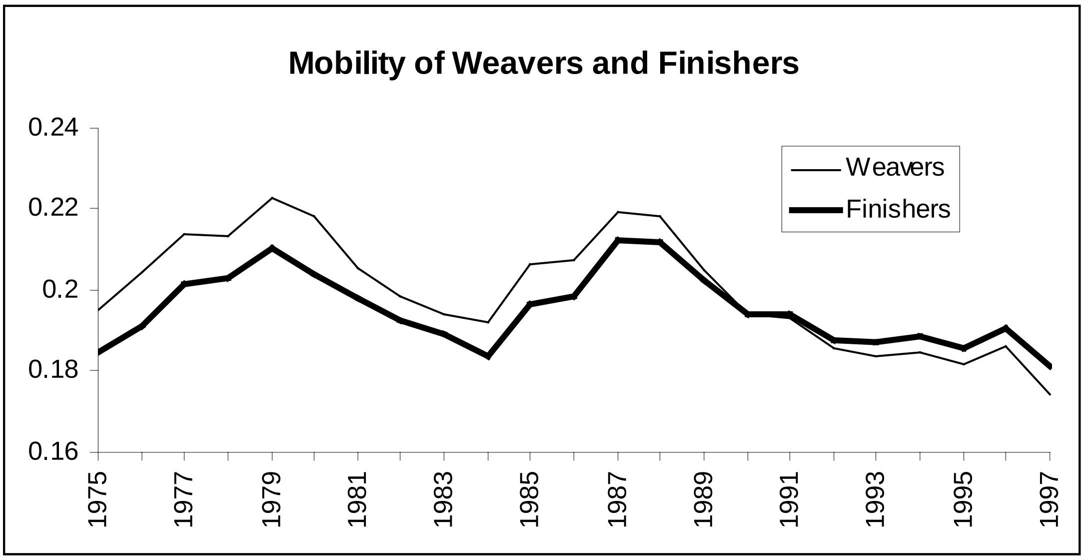
Mobility of Weavers and Finishers
0.24
0.22
0.2
0.18
0.16
Weavers
Finishers
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997

FIGURE 10