

INDIVIDUAL CONTACTS, COLLECTIVE PATTERNS

Prato 1975-97, a story of interactions

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Abstract

This article presents an agent-based model of an Italian textile district where thousands of small firms specialise in particular phases of fabrics production. It is an empirical model that reconstructs the communications between firms when they arrange production chains. In their turn, production chains reflect into the pattern of traffic in the geographical areas where the district extends.

1. Introduction

Firms are not scattered uniformly on earth surface. Rather, they concentrate at specific locations where they benefit both from the complementarities of buyer-supplier relationships and the knowledge- and productive base of competitors. This is particularly evident when local clusters are mainly composed by small and medium-sized firms which establish a thick web of interactions.

Economics has a long tradition with this subject. Marshall (1890) was first to notice the peculiar industrial structure that obtains when hundreds or thousands of small firms coexist at a specific place. Marshall stressed that an agglomeration in space of firms that operate in the same industry is 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.

This idea has been somewhat generalised by management studies, which typically focus on clusters of larger firms and competitive interactions (Porter 1990). Furthermore, economics has made use of geographical proximity in order to justify increasing returns at the industry level without giving up the assumption of decreasing returns at the level of single firms (Krugman 1991). The idea is that firms create a knowledge base in the area where they operate, which constitutes a positive externality for other firms.

These approaches have considered the effects of geographical proximity on economic activities as a sort of beneficial halo diffused on a territory. Albeit sufficient for macroeconomic descriptions, these accounts may be unsatisfying for geographers interested in the details of local development.

Hägerstrand suggested that social and economic geographers would keep track of daily movements of people (e.g. home to work, work to sporting activities etc.) and reconstruct the features of social organizations out of the structure of interactions of their actors (Hägerstrand 1970, 1982, 1985). Figure (1) illustrates his proposal (Hägerstrand 1985).

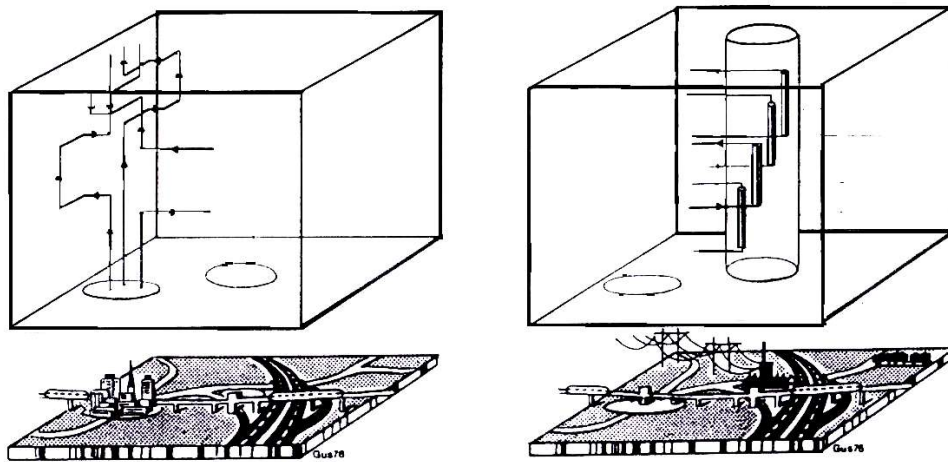


Figure 1

Interactions in space and time according to Hägerstrand (1985) ©.

Movements of people are constrained by time schedules as well as by constraints in space such as roads, private areas and so forth. At some points, e.g. working places, people have occasions to meet.

On the left side of figure (1) we see a residential area. Upon it, a cube where the x , y axes reproduce the geographical area while the z axis represents time. In time, people move on the area. On the left side of figure (1) we see a similar picture, this time of a workplace where people may have opportunities to come close to one another for relatively long times.

According to Hägerstrand, social geography should reconstruct the movements of people in space and time, highlighting to what extent these movements are shaped by physical geography. He called it *time-geography*. Potentially, this research program might have a large impact on many aspects of social geography (Pred 1977).

However, this research program was terribly hard to implement in the 1970s and 1980s, for it requires all movements of all agents to be observed. This situation has changed since the 1990s, when GISs have become available (Miller 1991; Kwan and Weber 2003). Detailed reconstruction of the movements of a large number of people has become possible (Kwan 1998, Weber and Kwan 2002). Furthermore, these empirical

investigations have shown that detailed microscopic description may yield different results from aggregate descriptions.

Quantitative descriptions might be integrated by models seeking to explain the emergence of certain patterns. This article has the purpose of presenting a modelling technique that suits Hägerstrand's "time geography".

The technique is *agent-based modelling*. This is a simulation methodology that reconstructs artificial worlds by modelling the behaviour of each single agent. Thus, its results may complement or integrate those obtained by means of detailed microscopic descriptions based on GIS data.

Several researchers are beginning to employ agent-based models to understand the behaviour of clusters of firms (Fioretti 2005). This article presents an application of agent-based modelling to a cluster of thousands of textile firms located in Prato, Italy. This area is famous because firms are very many, very small and often specialised in a tiny fraction of the overall production process (Becattini 1990). It is the a version of a simulation model employed to investigate the evolution of the competitive advantage of this system of firms (Fioretti 2001), run on a different set of data where information on the geographical location of firms is available.

This application shows how from information on the behaviour of single agents – in this case, firms – it is possible to reconstruct the overall pattern of interactions, which translate into flows of wares between geographical areas. Thus, this methodology may be used in order to evaluate the impact of economic activities on transportation infrastructures.

The rest of this article is organized as follows. Section 2 explains what agent-based models are. Section 3 illustrates this particular agent-based model. Section 4 discusses the data on which it is based. Section 5 checks the robustness of the model with respect to variations of its parameters. Section 6 illustrates the results of the model. Finally, Section 7 concludes.

2. Agent-Based Models

Agent-based models rest on a technique called *object-oriented programming*. Since practical concepts may be easier to grasp than abstract concepts, this section proceeds from the particular to the general. First, it reminds what a computer program is. Subsequently, it explains the idea of object-oriented programming. Finally, it arrives at the concept of agent-based models.

Traditional programming, sometimes called procedural programming, consists of:

- Instructions, such as value assignments and arithmetical operations of any kind;
- Conditions that command branching or looping over a set of instructions.

Figure (2) illustrates a possible structure of a piece of code. Programs may involve functions, i.e. pieces of code that are written separately and called at need, but this does alter their logical structure.

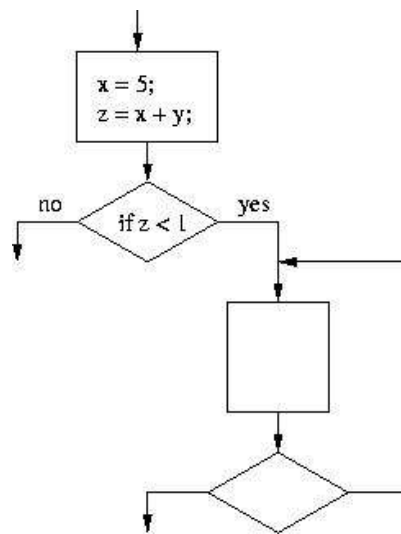


Figure 2

A typical flow chart of a procedural program. Instructions and conditions, where made explicit, should be meant as generic examples.

Flow charts may become very complicated as programs become very large. Since a programmer must overview all logical relations in a program, the cognitive burden may become unbearable.

Object-oriented programming consists of subdividing a computer program into relatively independent modules, called *objects*. Each object has the structure of a procedural program. Objects interact with one another by means of *methods*, which take the role of questions, answers or orders in the real life. Figure (3) illustrates a typical structure.

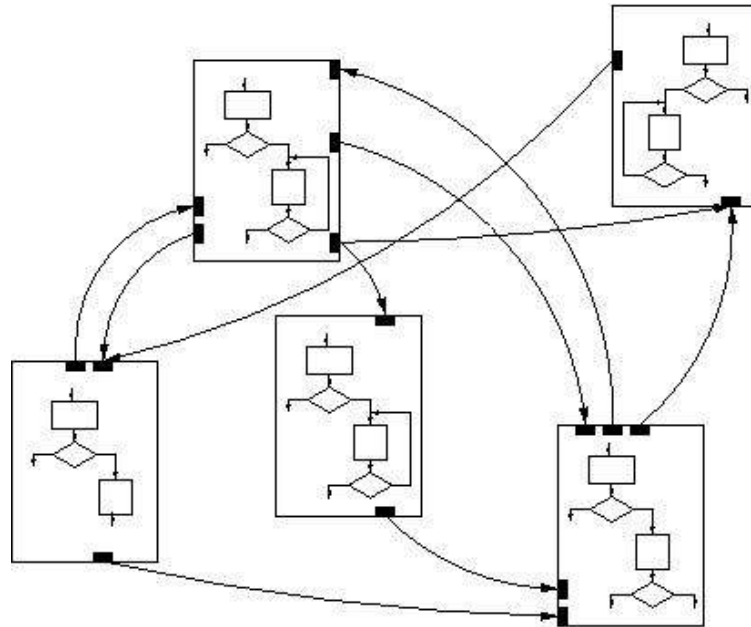


Figure 3

Computational objects (squares) and their relationships (arrows). Methods are denoted by black areas at the borders of objects. At any point in time, the objects are in a certain state of their flow diagram and only some of the depicted relations are taking place. Note that a method may issue/receive a communication to/from several other methods located in different objects.

Objects may entail different algorithms, in which case they are qualitatively different from one another. Or they may all entail the same algorithm, in which case they are said to be instances of a class of objects. However, even objects entailing the same algorithms may behave differently from one another if their parameters have taken different values depending on the history that they experienced. Since it is very easy to replicate instances of a class, objects may be very many.

A parallel may be traced with the behavior of natural beings. The DNA is the analogous of the algorithm that is inside an object. The DNA specifies a substantial part of the behavior of an animal, but not all of it. Even animals with the same DNA such as homozygote twins - natural clones - may behave differently because they make different experiences so their basic algorithm specializes into different responses. In humans, this effect is paramount: Everyone knows that homozygote twins, though identical in appearance, may have very different characters and personalities. Coming back to the context of object-oriented programming, objects with the same algorithm may behave very differently depending on the parameters with which they are initialized and the communications that they entertain with other objects.

Object-oriented programming lends itself very naturally to social simulation. In fact, it is straightforward to think of social actors as computational objects. Since computational objects that represent social actors are generally endowed with a substantial degree of autonomy and with sophisticated cognitive abilities, they are generally called *agents*. Hence the expression “agent-based models”.

Agent-based models are good at generating emergent macroscopic behavior. Of course, a necessary condition is that microscopic agent behavior is known reasonably well.

Agent-based models are appropriate when aggregate behavior depends on structures of relations, so it cannot be ascribed to a fictitious “representative agent” (Kirman 1992). More flexible than differential equations and yet more precise than verbal descriptions, agent-based models offer to the social sciences a descriptive language that attains sharpness retaining the richness of verbal accounts (Gilbert and Terna 2000).

3. This Model

This model aims at reconstructing the evolution of the structure of interactions between Pratese firms during an extended period of time, 1975 through 1997. Interactions are customer-supplier relationships that are

arranged by middlemen, a special class of firms that have contacts with international buyers.

At the beginning of each year, the model takes as input the number of firms specialised in each production phase. No population dynamics is modelled. Implicitly, economic equilibrium is assumed.

At the beginning of each year, firms are placed on a space of acquaintances where they move according to the arrangements that they make with each other. Eventually, a middleman receives an order from a buyer and arranges the other firms in production chains that depart from it.

Figure (4) illustrates a snapshot of the model. Dots represent firms in the space of acquaintances, i.e. the closer they are, the better they are acquainted with one another. Stripes of firms represent production chains, i.e. a set of firms that are carrying out a sequence of operations yielding the final product. The middleman is at the beginning of a stripe; eventually, two or more stripes may depart from the same middleman.

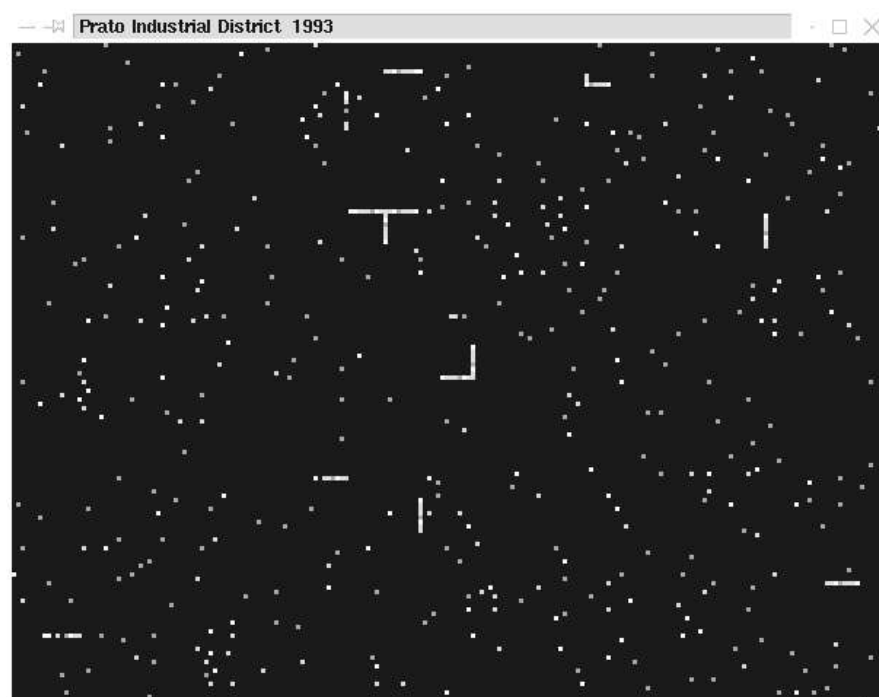


Figure 4

The space of acquaintance where firms move. This space is a torus, i.e. each end borders with the opposite one. In the original picture, colours identify the production phase of a firm.

Middlemen do not arrange firms in any order. There are ten types of firms, that differ from one another according to the production phase that they are able to carry out. For instance, there are warpers and there are weavers.

Furthermore, production chains may differ from one another. For instance, production may make use of carded spinning or combed spinning. Certain semi-finished goods may be purchased by a supplier or they may be produced within the chain. All these possibilities are entailed in the “DNA” of middlemen, the algorithm that specifies their possible behaviour.

The algorithms that describe the behaviour of middlemen and the other firms have been written upon careful examination of the empirical literature. Thus, they constitute an important empirical input of the model (the other being the number of firms at the beginning of each year). These algorithms have been written out of the following considerations.

The technologies and production processes that have been employed in Prato in the period 1975-97 were still influenced by a focus on the lower segments of the market. Traditionally, Prato made low-quality, low-price textiles out of regenerated wool. This picture changed during the 1980s, but many organizational arrangements survived.

Regenerated wool is obtained from threadbare clothes and rags of 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 one 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. Since the 1990s wool regeneration disappeared in Prato, but still, for historical reasons, most Pratese firms produce 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 are refined by a series of 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 with time.

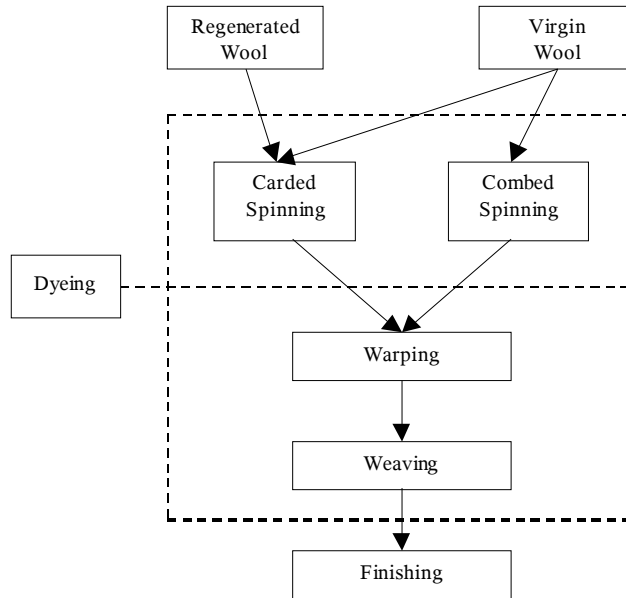


Figure 5

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

least as a first approximation does make sense given the small size of the area (the province of Prato is, roughly, a rectangle of 10×50 Km). However, a more precise model should describe the topology of acquaintances as it is moulded by family ties, affiliation to professional associations and – last but not least – geographical proximity.

For each year the simulation goes through a large number of steps in order to make the model explore the whole space of possibilities. At each step, all firms except the middlemen make a random move in the area. In particular, traders of finished products look for a middleman. As soon as they detect one 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 of 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 a production chain has been completed. Appendix A illustrates the behaviour of single firms in more detail.

In the end, selection of one out of the eleven possible production chains depends on which firms are nearest to the middleman in acquaintance space. This depends on how many firms of each type were available in a particular year, as well as on which firms have been contracted by a middleman during the previous steps.

In fact, at the end of each step all production chains are destroyed and their component firms are set free. However, if a trader of finished products remains close enough to a middleman, the next step it will prompt the construction of a production chain attached to the same middleman. So if also the other firms did not jump too far in the meantime, it is quite possible that the very same production chain will be reconstructed.

However, it is worth to note that even if a middleman constructs a production chain with the same component firms through two or more consecutive steps, these chains are not necessarily identical with one

another. In fact, figure (6) makes clear that it is possible to arrange a given set of firms according to several sequences.

Thus, the model is path-dependent because production chains are chosen depending on the position of firms in acquaintance space. However, stability of results is achieved by performing very many simulation steps for each year and by running the model with many different initial droppings of firms.

The number of steps is chosen as follows. In order to obtain reliable results, the number of interactions must be kept nearly constant each year. Thus the number of steps in year y , denoted by $s(y)$, is chosen such that $s(y)n(y) = c$, where $n(y)$ is the number of firms in year y and c is a constant. It was observed that $c=1,000,000$ is sufficient to yield smooth results.

The code has been written in objective C on the *Swarm-2.2* platform. It is free software, available at <http://econwpa.wustl.edu/eprints/prog/papers/0210/0210001.abs> under the terms of the GNU public license. Swarm is available at <http://wiki.swarm.org>.

4. The Data

The data on the number of firms of the selected ten types have been collected by *Istituto Nazionale per la Previdenza Sociale*, the Italian agency for social insurance (INPS 2001).¹ These data cover all firms that have at least one employee, for whom they must pay social benefits to INPS.² For the period from 1975 to 1997 there are records of all firms in the province of Prato, their names and addresses, a brief description of their activity and the number of their employees. From this description, and to a lesser extent

¹ Data have been kindly provided by Prof. Giuseppe Tattara of the University of Venice, who accessed them in the framework of MIUR 2001.20011134473.

² This is, namely, the most severe limitation of these data. In fact, a number of Pratese firms are composed by one or a few owners/workers, often members of the same extended family. Since they have no employees, they do not appear in this database.

from the names of the firms, I constructed a database that specifies in which phase of the production process a firm is specialised (warping, weaving, etc.).

The details of these classification criteria are explained in Appendix B. However, the following issues deserve some attention:

- 1) Almost no firm carried out more than one operation, except for a very limited number of dyeing plants that performed finishing operations as well. In these very few cases, a firm appears twice in the final dataset, i.e. both in the list of dyeing plants and in the list of finishers.
- 2) Some large woollen mills have been included among the middlemen. In fact, the model focuses on that part of their production that exceeds their productive capacity, for which they eventually contract other firms.

The model aims at reconstructing the orders that middlemen place to the firms that they contract. 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 firm size but we do not have any information on lot size, we must proceed by making hypotheses and explore their consequences:

- H 1. Lot size is proportional to firm size, i.e. larger firms process larger lots. Consequently, the size of firms does not influence the number of orders that they process.
- H 2. Lot size is independent of firm size. Consequently, larger firms process a larger number of orders.

Clearly, the above hypotheses are extremes. Thus, the results obtained with them are likely to provide the extremes of an interval where the real values lie.

If hypothesis (1) is chosen, all firms have the same number of interactions per unit time, independent of their size. If hypothesis (2) is chosen, larger firms have more interactions per unit time, possibly with different firms at the same time. A simple way to deal with this problem is to define the number of agents in the simulation as follows:

1. If hypothesis (1) is accepted, then the number of agents is equal to the number of firms;
2. If hypothesis (2) is accepted, then the number of agents is equal to the number of firms multiplied by their employees.

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.

5. Robustness

Before exposing the results of the model, let us check whether they are robust with respect to variations of the parameters. This ensures that the conclusions of the model reflect genuine empirical phenomena.

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 space of acquaintances where agents are placed. With hypothesis (1) there are, roughly, 2,000 to 3,000 agents each year; with hypothesis (2) they are 20,000 to 30,000. In the first case, a choice of parameters that yield sensible results is a variance of 10.0, a watching area of 100 pixels and a space of acquaintances of 300,000 pixels. In the second case, the size of the space of acquaintances must be increased to 3,000,000 pixels.

In order to evaluate the sensitivity of the model with respect to these parameters, six series of five simulations have been run. In each series, a parameter was decreased or increased 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 space of 270,000 pixels and five times in a space of 330,000 pixels. In the case of hypothesis (2), same as before except that the model was run first in a space of 2,700,000 pixels, then in a space of 3,300,000 pixels.

The effect of these variations of parameters was measured on the relative proportions of the eleven different production chains that the model is able to reconstruct. For instance, the proportion of production chains constituted of “Trader Raw Materials” → “Dyeing Plant” → “Carded Spinning” → “Warper” → “Weaver” → “Finisher” → “Trader Finished

Products” is represented by a curve with one point for each simulation year from 1975 to 1997. The curve obtained by changing a parameter can be compared with the curve obtained when parameters are at base values by calculating its mean square error.

Table 1 illustrates the mean square error across the 23 simulation years and the 11 production chains calculated on 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 mean 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. The differences between different simulations with the same (base) parameter values are due to random dropping of firms, random movements on the acquaintance space and random choices within the watching range.

Table 1

	Hypothesis 1	Hypothesis 2
Variance – 10%	0.000017	0.000015
Variance + 10%	0.000013	0.000013
Watching Area – 10%	0.000022	0.000016
Watching Area + 10%	0.000023	0.000014
Size of Space – 10%	0.000035	0.000018
Size of Space + 10%	0.000022	0.000022
Base Parameter Values	0.000022	0.000010

According to table 1, variations of the parameters in a $\pm 10\%$ range generate errors that are of the same order of magnitude than the random variations exhibited by simulations with parameters at base values. In relative terms, the model is most sensitive to variations of the size of the space of acquaintances.

6. The Results

By simulating encounters in acquaintance space, the model reconstructs communications between firms. These communications give rise to chains of production and, ultimately, to flows of goods between firms.

Thus, once communications have been reconstructed it is possible to derive the structure of the traffic of wares in physical space. In fact, if a middleman arranges a production chain that involves a warper at a place A who must ship his product to a weaver at a place B, then this production chain generates traffic from A to B. However, since this model reconstructs the structure of interactions but not their true number, only percentages of traffic can be given.

The province of Prato is composed by seven administrative areas: *Cantagallo*, *Carmignano*, *Montemurlo*, *Poggio a Caiano*, *Prato*, *Vaiano* and *Vernio*. The model is able to reconstruct the shares of traffic within and between each area.

Figure (7) illustrates (top to bottom) the percentages of traffic within the areas of *Prato*, *Montemurlo*, *Vaiano* and *Cantagallo*. Note that, since the percentage of traffic within *Prato* is much larger than the percentage of traffic within *Cantagallo*, the curves have been depicted on a logarithmic scale. The more peripheral areas of *Carmignano*, *Poggio a Caiano* and *Vernio* could not be depicted because their percentages of traffic was so small that it made all other curves look flat. Figure (7) has two curves for each administrative area, that have been derived under hypotheses (1) and (2), respectively.

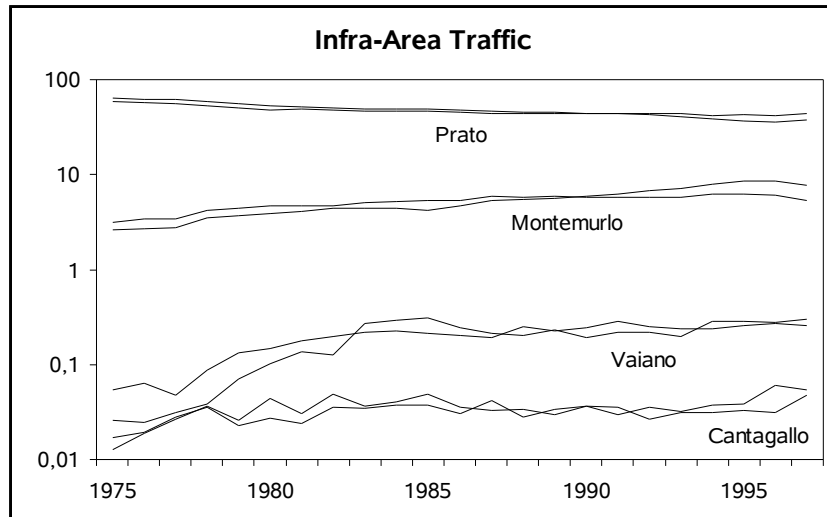


Figure 7

Percentages of wares traffic within *Prato*, *Montemurlo*, *Vaiano* and *Cantagallo* due to the textile industry, from 1975 to 1997. Averages over ten simulation runs at base parameter values.

For each of the above regions, two curves are drawn depending on whether data have been handles according to hypothesis (1) or (2), respectively. The true values must lie in the region between them.

Figure (7) highlights quite different patterns of development of traffic within each area. Albeit compressed by the logarithmic transformation, the curves of traffic within the *Prato* area show a continuous decrease of traffic. This implies a process of gradual diffusion of the textile industry from the town of *Prato* to its surroundings. Interestingly, this process slowed down during the 1980s, when the Pratese textile industry was in crisis.

Montemurlo, at a distance of just 6 from the town of *Prato* and in the process of forming a single agglomerate with it, has taken the greatest advantage from this diffusion. The increase of the percentage of traffic within *Montemurlo* did not suffer from the crisis of the 1980s. *Vaiano* increased its share of infra-area traffic from the mid 1970s to the mid 1980s, then stalled. Finally, *Cantagallo* increased its share during the second half of the 1970s and possibly during the second half of the 1990s as well, but stalled in between.

However interesting, infra-area traffic cannot be considered as an indicator of economic development. Rather, infra-area traffic indicates the extent to which a geographical area is a self-contained economic unit, with the proper number of each kind of specialised firms in it. But, development of the textile industry could be also achieved with, say, *Prato* specialising in trading and *Cantagallo* specialising in weaving, which would cause a large amount of traffic between these two areas but little traffic within them.

Figures (8) and (9) illustrate the shares of inter-area traffic in 1975 and 1997 calculated under hypothesis (1) and (2), respectively. The thickness of lines reflects the share of traffic in logarithmic scale.

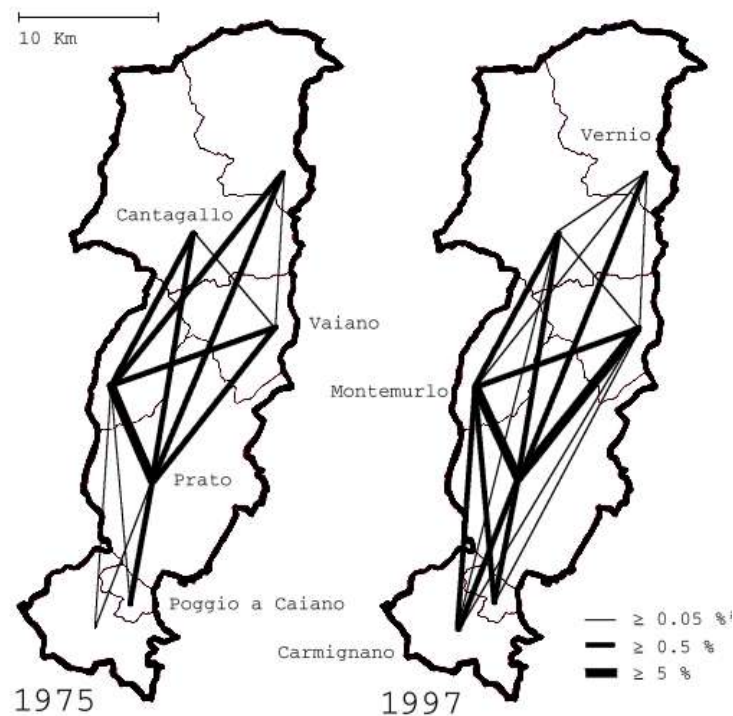


Figure 8

Traffic between the administrative areas of the Prato province as percentages of total traffic, calculated under hypothesis (1). Simulation outcomes have been averaged over ten runs at base parameter values. Years 1975 (left) and 1997 (right).

The traffic within areas has not been depicted. The end points of segments do not reflect the physical location of main towns.

For the year 1975, the numerical values greater or equal to 0.05% (two-digits approx) are: *Cantagallo-Montemurlo* 0.51%, *Cantagallo-Prato* 1.93%, *Cantagallo-Vaiano* 0.07%, *Carmignano-Montemurlo* 0.08%, *Carmignano-Prato* 0.27%, *Montemurlo* 3.19%, *Montemurlo-Poggio* 0.26%, *Montemurlo-Prato* 26.80%, *Montemurlo-Vaiano* 0.88%, *Montemurlo-Vernio* 0.54%, *Poggio-Prato* 1.16%, *Prato* 58.63%, *Prato-Vaiano* 3.62%,

Prato-Vernio 1.79%, *Vaiano* 0.05%, *Vaiano-Vernio* 0.07%. For the year 1997, the numerical values greater or equal to 0.05% (two-digits approx) are: *Cantagallo* 0.05%, *Cantagallo-Carmignano* 0.05%, *Cantagallo-Montemurlo* 1.11%, *Cantagallo-Prato* 2.72%, *Cantagallo-Vaiano* 0.24%, *Cantagallo-Vernio* 0.05%, *Carmignano-Montemurlo* 0.82%, *Carmignano-Prato* 2.77%, *Carmignano-Vaiano* 0.19%, *Montemurlo* 5.28%, *Montemurlo-Poggio* 0.51%, *Montemurlo-Prato* 29.53%, *Montemurlo-Vaiano* 2.43%, *Montemurlo-Vernio* 0.45%, *Poggio-Prato* 1.70%, *Poggio-Vaiano* 0.10%, *Prato* 43.83%, *Prato-Vaiano* 6.47%, *Prato-Vernio* 1.15%, *Vaiano* 0.26%, *Vaiano-Vernio* 0.09%.

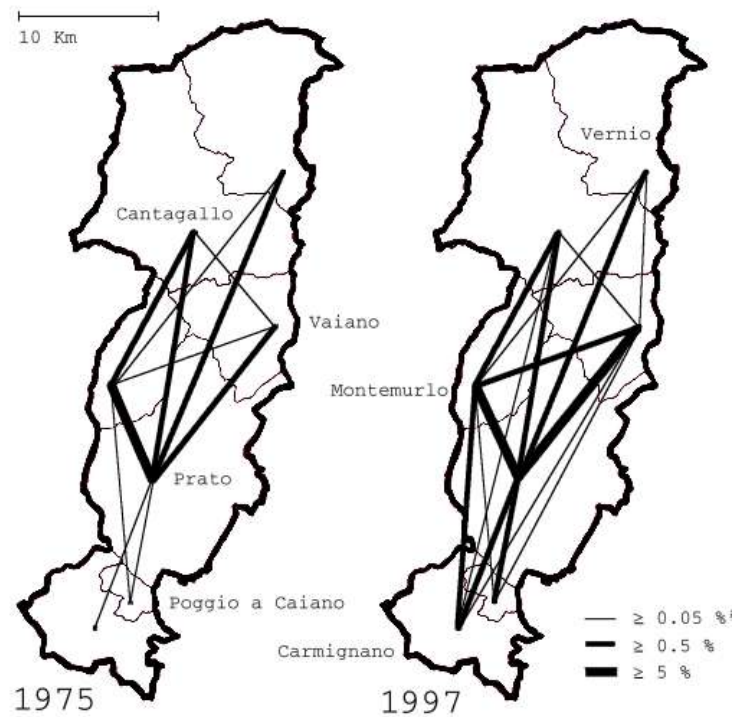


Figure 9

Traffic between the administrative areas of the *Prato* province as percentages of total traffic, calculated under hypothesis (2). Simulation outcomes have been averaged over ten runs at base parameter values. Years 1975 (left) and 1997 (right).

The traffic within areas has not been depicted. The end points of segments do not reflect the physical location of main towns.

For the year 1975, the numerical values greater or equal to 0.05% (two-digits approx) are: *Cantagallo-Montemurlo* 0.54%, *Cantagallo-Prato* 2.04%, *Cantagallo-Vaiano* 0.06, *Carmignano-Prato* 0.05%, *Montemurlo* 2.60%, *Montemurlo-Poggio* 0.07%, *Montemurlo-Prato* 25.73%, *Montemurlo-Vaiano* 0.58%, *Montemurlo-Vernio* 0.34%, *Poggio-Prato* 0.42%, *Prato* 63.27%, *Prato-Vaiano* 2.94%, *Prato-Vernio* 1.22%. For the year 1997, the numerical values greater or equal to 0.05% (two-digits approx) are: *Cantagallo-Carmignano* 0.08%, *Cantagallo-Montemurlo* 1.35%, *Cantagallo-Prato* 2.70%, *Cantagallo-*

Vaiano 0.24%, *Carmignano-Montemurlo* 1.00%, *Carmignano-Prato* 2.43%, *Carmignano-Vaiano* 0.17%, *Montemurlo* 7.78%, *Montemurlo-Poggio* 0.48%, *Montemurlo-Prato* 33.84%, *Montemurlo-Vaiano* 3.09%, *Montemurlo-Vernio* 0.28%, *Poggio-Prato* 1.27%, *Poggio-Vaiano* 0.06%, *Prato* 37.33%, *Prato-Vaiano* 6.75%, *Prato-Vernio* 0.63%, *Vaiano* 0.30%, *Vaiano-Vernio* 0.05%.

According to figures (8) and (9), the structure of traffic changed dramatically between 1975 and 1997. In 1975, *Prato* and *Montemurlo* monopolised any relationship the other areas had. In fact, on the left side of figures (8) and (9) we can observe a very thick line between *Prato* and *Montemurlo* and, from both of them, lines of various thickness towards other areas. On the contrary, in 1997 firms in the other areas were much more likely to interact directly with one another, which reflects into much more intertwined structures on the right side of figures (8) and (9).

This development is caused by specialisation of some areas in one or a few phases of production. It causes traffic to increase with a power law of economic development, which poses huge problems on transportation infrastructures.

Figure (10) allows us to compare the geographical distribution of traffic reconstructed in figures (8) and (9) with the structure of roads in the province. On the right sides of figures (8) and (9) we can see that the area around the town of *Prato* (the *Prato – Montemurlo – Vaiano* triangle) is the one where traffic increased most. On figure (10) we can see that this is also the area where roads are best developed.

Note that the development of traffic is not closely related to the absence of mountains. For instance, the southern end of the province (*Carmignano, Poggio a Caiano*) is nearly as plain as *Prato* and *Montemurlo*, but the traffic of wares developed to the same extent as the northern mountainous end (*Cantagallo, Vernio*).

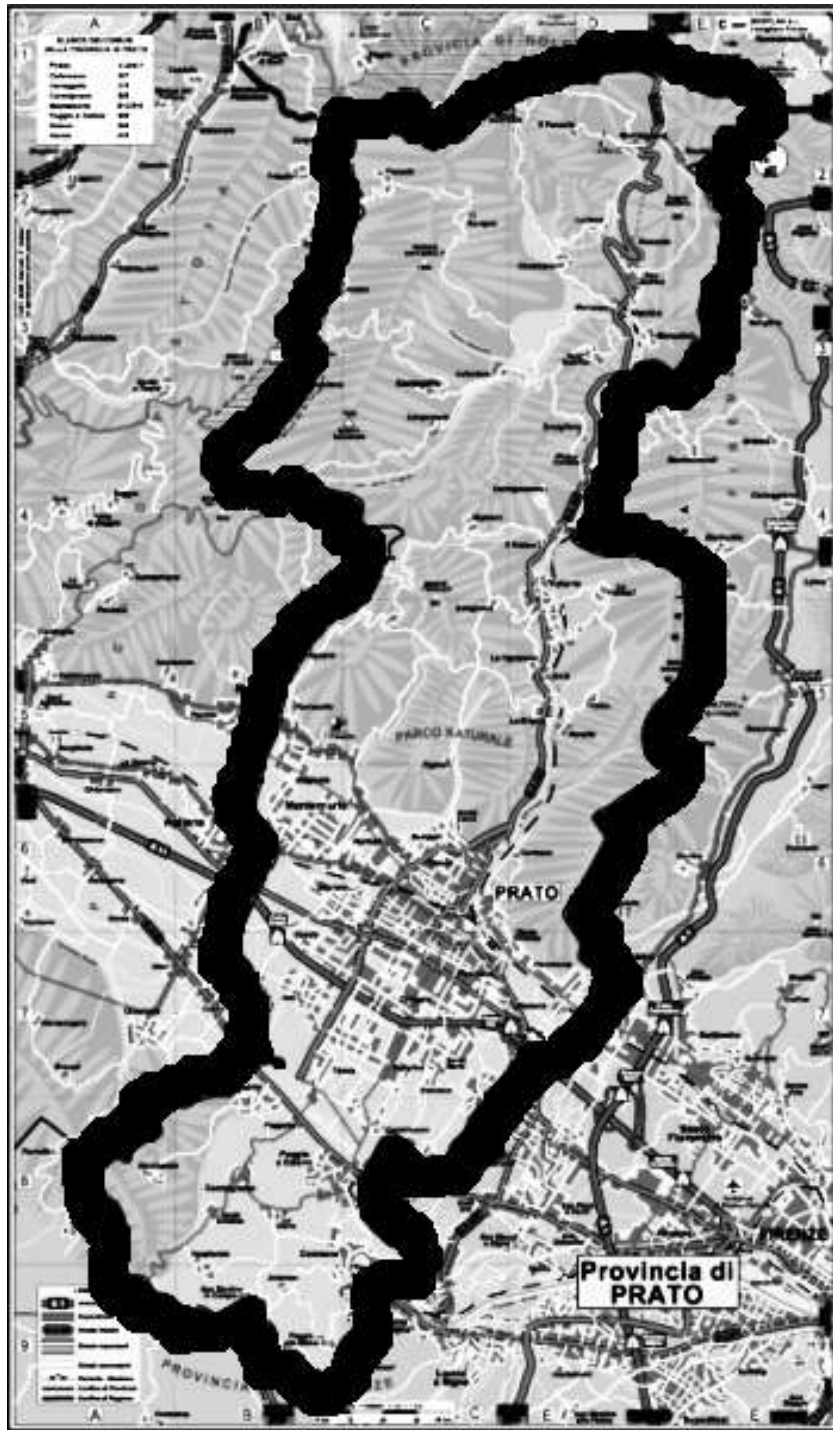


Figure 10

The province of Prato, with its roads (dark grey, white) and an indication of mountains (grey). The wide dark stripe south of Prato is a motor road, presumably not used by local traffic. The dashed line is the Florence-Bologna railway, also irrelevant to this analysis.

7. Conclusions

This article expounded agent-based modelling with respect to the very simple requirement of reconstructing the dynamics of traffic induced by economic activities in a specific area. It did not attempt to explain why a certain economic development took place, though agent-based models can be used to address questions of this kind as well. It simply read the data and re-arranged them in such a way that certain features were highlighted.

No additional information was created so, in principle, all conclusions could have been drawn from careful reading of the data on the geographical distribution of firms having in mind the technological constraints to which they were subject. However, such a reading would have been extremely cumbersome, and in fact, although the data have been available for years, nobody ever attempted a quantitative estimation of the traffic structure ensuing from the activities of the textile industry in Prato.

This is not different from other means for handling data. For instance, when fitting a regression curve one does not obtain novel information. Simply, the information entailed in the data is expressed in a meaningful way.

Agent-based models should be used in order to verify or investigate statements that regard the formation of structures between interacting agents. Many social and economic problems have this feature, especially when agents are scattered in space.

Unfortunately, very few relational data – such as e.g. the size of lots exchanged between firms – are available. This is not the kind of data that are collected by statistical institutes, and yet this is the kind of data that are needed in order to build realistic and reliable agent-based models.

The model presented herein did not pretend to be a reliable guide to the estimation of traffic flows. In order to make such a claim, the outcome of the model should be checked against detailed data on the relationships between a subset of firms. This is not feasible today, but it may be tomorrow. Potentially, agent-based models can be a powerful tool in the hands of “time-geography”.

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Appendix A

This appendix expounds the behaviour of the agents in the model by means of flux diagrams. These diagrams represent the logic of their algorithms.

At each step, the story begins with the traders of finished products. The traders of finished products walk around in acquaintance space, look around in their watching range and, if they find a middleman, they move close to it and place an order. The corresponding flux diagram is expounded in figure (A1).

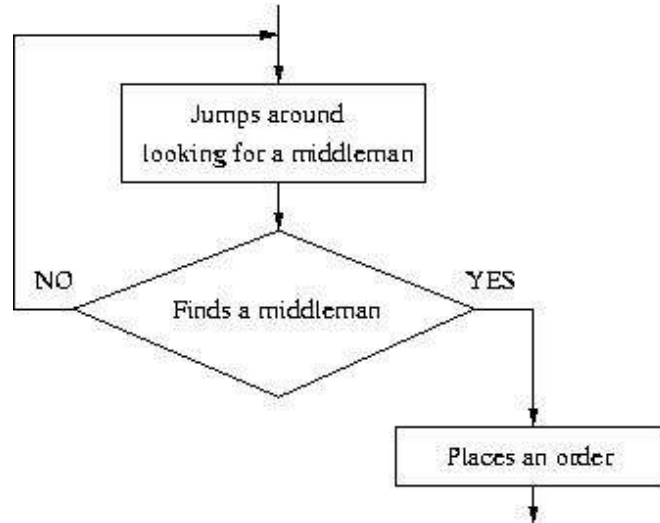


Figure A1

A trader of finished products jumps around in acquaintance space, looks for a middleman and, if he finds one, places an order.

Middlemen, as soon as they receive an order, begin to look around in order to find firms to build production chains. The kind of chain that they build depends on which firms are closest to them in acquaintance space. Figure (A2) illustrates the algorithm employed by the middlemen.

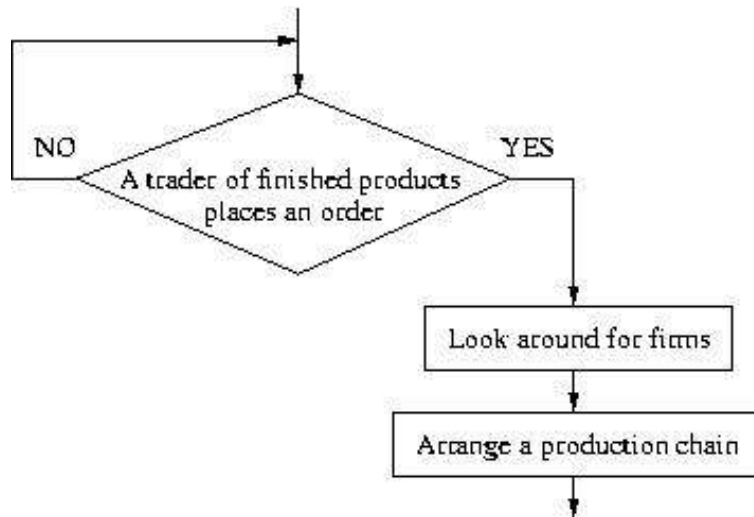


Figure A2

A middleman receives an order, looks around for firms and arranges a production chain.

The other firms are alike in their behaviour. All of them jump around in acquaintance space – i.e. they try to become acquainted with as many forms as possible - until a middleman calls them to be part of a production chain. Figure (A3) illustrates this algorithm.

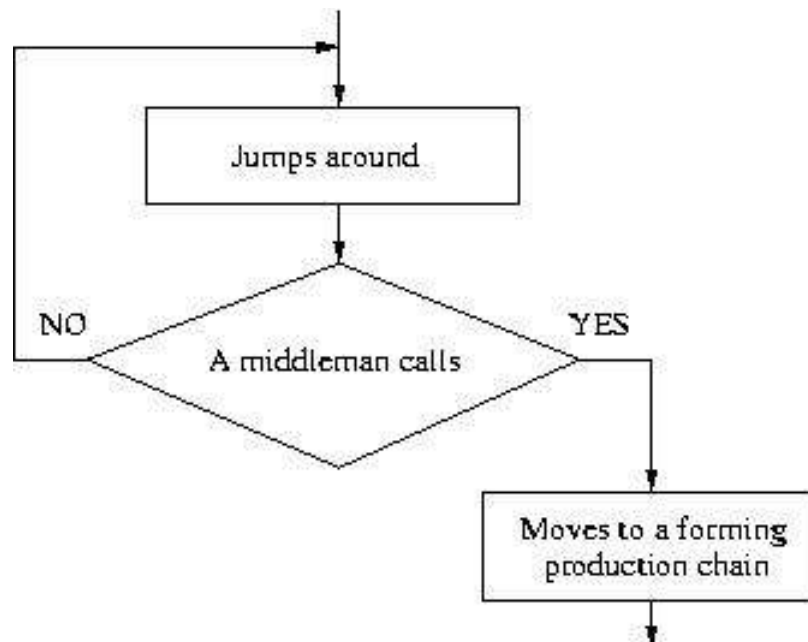


Figure A3

The other firms jump around in acquaintance space until a middleman calls them to be part of a production chain.

The above sequence repeats itself for all traders of finished products, all middlemen and all other agents. This is a simulation step. At the end of each step all chains are destroyed and a new step begins.

Appendix B

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 [spun 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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