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 (ABM) of an Italian textile district where thousands of small firms specialize in particular phases of fabrics production.

It is an empirical model because it reconstructs the communications between firms when they arrange production chains. In their turn, production chains reflect into the pattern of road traffic in the geographical areas where the district extends.

It is a methodological model because it aims to show that ABMs can be used to reconstruct a web of movements in geographical space. ABMs are proposed as a tool for Hägerstrand's "time-geography".

1. Introduction

Firms are not scattered uniformly on earth surface. Rather, they concentrate at specific places 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 an *industrial district*.

This idea has been somewhat generalized by management studies, which typically focus on clusters of larger firms and competitive interactions (Porter 1990). Furthermore, economics has explained the concentration of manufacturing activities by means of the demand for manufactured goods caused by local production (Krugman 1991a, 1991b). The idea is that the income generated by manufacturing activities provides a local market for other manufacturing activities which, if transportation costs are sufficiently low, have an incentive to locate close to one another.

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 theory, these accounts may be unsatisfactory for geographers interested in explaining the local development of a particular area. In fact, it is often necessary to reconstruct the evolution of the network of relationships between firms and other institutions in order to understand why a local economy developed along a specific path.

Several scholars investigated the structure of local interactions within an industrial district, or cluster of firms. Rabellotti (1998) studied four clusters of footwear producers, in Italy and in Mexico. She analyzed the subcontracting relations with respect to stability and degree of cooperation, as well as the relations between firms working in the same production phase with respect to collaborative and institutional efforts. Nahm (1999) found that the fortune of the old office quarter of central Seoul is due to the possibility of informal contacts between headquarters, and that this force is much stronger than the availability of better and cheaper facilities in neighboring areas. Jou and Chen (2001) studied the network of relationships of the main IC producers in the Hsinchu cluster, Taiwan. They found that networks substitute for vertical integration and that international networks have been built along with industry maturation. Beerepoot (2005) studied the stability and technological content of the subcontracting relations in two furniture districts in the Philippines. In this case, the structural differences between the networks of relations in the two districts reflect into their economic performance. Gaggio (2006) highlighted that the development of two Italian gold jewelry districts cannot be understood without unraveling the networks of relations between local firms, political powers and groups of interests. Finally, Boschma and ter Wal (2007) challenged the view that space proximity naturally translates into a uniform diffusion of knowledge. They analyzed the network of relations in the Barletta footwear district, Italy, finding that only a few firms are able to draw information from other firms in the district. All these studies testify a growing interest in the structure of relations as a determinant of the dynamics of clusters of firms.

This growing wave of attention to the details of network relations is welcome by theoretical considerations (Lane 2002; Gaggio 2006; Nooteboom 2007), but lacks appropriate tools for formal implementation. This article aims to present a candidate tool for this approach, namely, agent-based computational modeling. It does so by presenting an agent-based model of the Prato textile district, Italy, where commercial contacts and shares of road traffic are derived from information regarding the typical behavior and physical location of its component firms.

However, this proposal does not come to social and economic geography as an injection of a foreign piece of knowledge. In fact, although agent-based computational models may be novel to most social geographers, much of their spirit has been foreseen by the late T. Hägerstrand.

In fact, Hägerstrand suggested that social and economic geographers should 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).

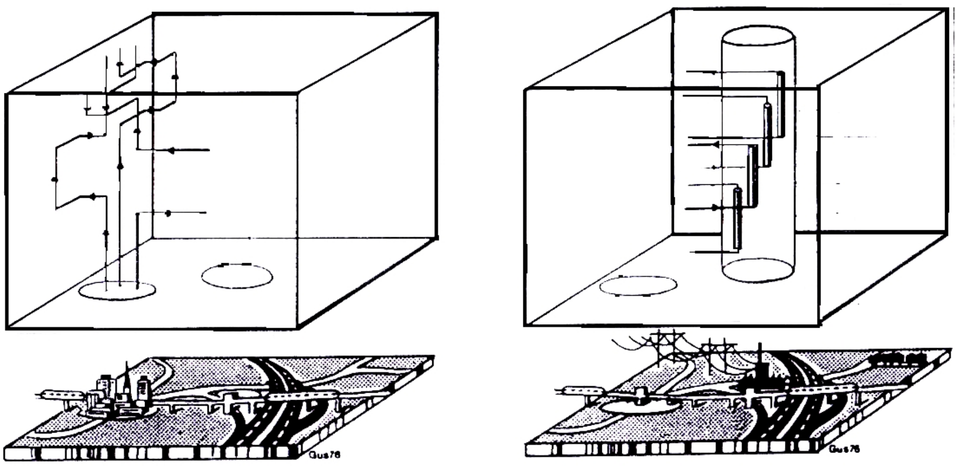

Figure 1
Interactions in space and time according to Hägerstrand (1985) ©.

Hägerstrand stressed that the 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. This combination of constraints to movements and opportunities for encounters can be captured by *prisms* that entail the actual trajectories of social actors in space.

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. *Time-geography*, as he called this research program, was expected to have a large impact on many aspects of social geography (Pred 1977). However, *time geography* was terribly hard to implement in the 1970s and 1980s, for it required all movements of all agents to be observed.

This situation has started to change since the 1990s, when GISs have become available (Miller 1991; Kwan and Weber 2003) so detailed reconstruction of the movements of a large number of people has become possible (Kwan 1998; Kwan and Weber 2003). The empirical investigations enabled by GISs have shown that detailed microscopic description may yield different results from gravitational or other aggregate models. In particular, gender differences in the usage of time, behavior induced by time windows such as working times and rush hours, as well as zooming the scale of description cannot be rendered by aggregate models (Kwan and Weber 2003).

Agent-based modeling is a simulation technique that reconstructs artificial worlds by modeling the behavior of each single actor in a community. 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 behavior of clusters of firms (Fioretti 2006). The model presented in this paper has a demonstrative purpose. It wants to show that from information on the typical behavior of single firms it is possible to reconstruct the overall pattern of interactions, which translate into flows of traffic between geographical areas. Thus, it is possible to infer the shares of traffic load on local roads, with obvious implications for the evaluation of 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 generally rest on a technique called *object-oriented programming*. Since practical instances 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 computer 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.

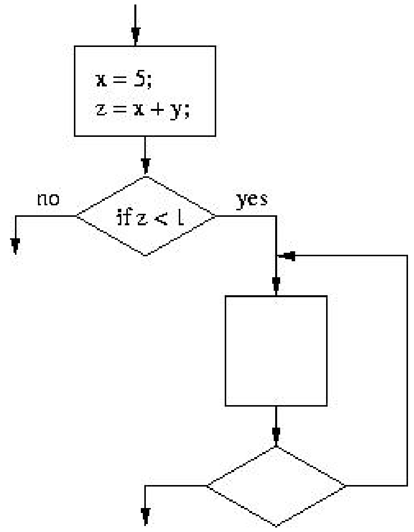

Figure 2
A typical flow chart of a procedural program. Instructions and conditions, where made explicit, are meant as generic examples.

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 same role that questions, answers or orders have in real life. Figure (3) illustrates a possible structure.

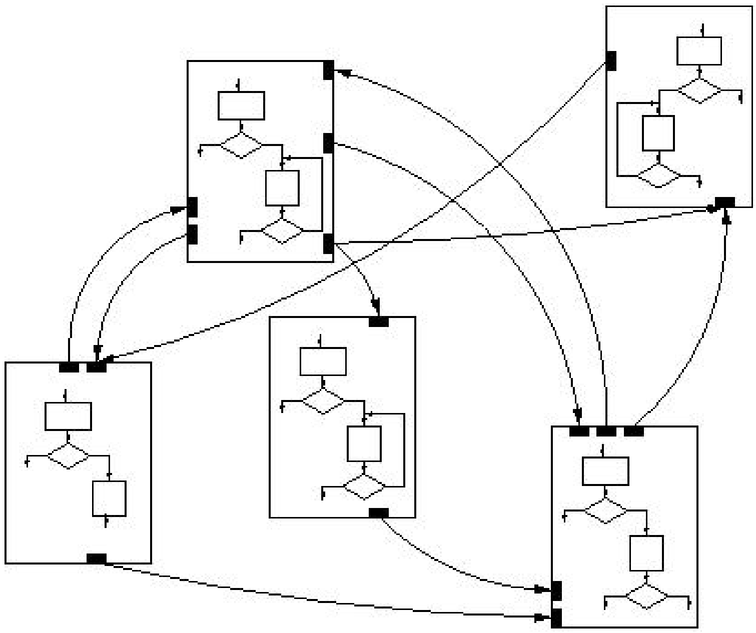

Figure 3
Computational objects (squares) and their relationships (arrows). Methods are denoted by black areas at the borders of objects. At any point in time, the objects are in a certain state of their flow diagram and only some of the depicted relations are taking place. Note that a method may issue/receive 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 can be very many.

A parallel may be traced with the behavior of natural beings. The DNA is their 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. 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 have been initialized and the communications that they entertained 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. For instance, it is possible to think of firms in an industrial district as computational objects in an artificial space (Fioretti 2006).

Since the computational objects that represent social actors are generally endowed with a substantial degree of autonomy as well as 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 (e.g., of an industrial district) out of knowledge of microscopic agent behavior (e.g., of its component firms). Agent-based models are appropriate when aggregate behavior depends on the structure 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 while retaining the some of the richness of verbal accounts (Gilbert and Terna 2000).

3. This Model

This article presents an application of agent-based modeling to a cluster of thousands of textile firms located in Prato, Italy. This area has come to be seen as a prototypical industrial district characterized by a large number of firms, generally very small and often specialized in a tiny fraction of a production process that is largely self-contained within the district (Becattini 1990). To a lesser extent, in the 1960s through the 1970s and 1980s these features could be found in other industrial districts as well, in Italy and elsewhere.

Since the 1990s and with a sharp acceleration at the turn of the century, industrial districts around the world have started to change their nature. In fact, albeit local relations are still paramount, substantial parts of their production processes are often carried out outside their traditional area of operation (Maskell and Malmberg 1999; Leamer and Storper 2001; Phelps and Ozawa 2003). In particular, in Prato and elsewhere firms have become quite heterogeneous both with respect to size and innovative capability (Whitford 2001; Cainelli, Iacobucci and Morganti 2006; Di Maria and Micelli 2007). Thus, the turn of the century marks a transition in the very nature of Prato. We shall refer to the structure of this productive system in the second half of the XX century as to the *classical* Prato.

Agent-based modeling can be applied to industrial districts of any kind, including those where actors have different size and entrepreneurial capabilities. However, only a few data are available for the years after the transition. On the contrary, the classical Prato is covered since 1975 by INPS data (see references). Furthermore, while the operation of the classical Prato is uncontroversial, the real working of contemporary Prato is a subject of debate. Since this article has the purpose of showing a methodology, it wants to avoid all controversial issues regarding the object to be modeled. The threshold at 1997 is somewhat arbitrary, but it reflects a real discontinuity besides availability of data.

The model has been successfully employed to investigate the evolution of the competitive advantage of this system of firms (Fioretti 2001). By running it on a different data set, where information on the geographical location of firms is available, this article reconstructs business interactions and traffic shares between different geographical areas.

For each year 1975 to 1997 the model takes as input the number of firms specialized in ten production phases: The number of (1) Traders of Raw Materials, of (2) Rags Collectors, of (3) Carded Spinnings, of (4) Combed Spinnings, of (5) Warpers, of (6) Weavers, of (7)

Dyeing Plants, of (8) Finishers, of (9) Traders of Finished Products and of (10) Middlemen. No population dynamics is modeled. Implicitly, economic equilibrium is assumed. The assumed output of all production processes in the Prato district is fabrics.

At the beginning of each year, firms are placed on a torus that represents the space of acquaintances in the district. The space of acquaintances is derived from geographical space by considering all physical and social artifacts that ease or hinder acquaintances between firms. In a very rough first approximation one may assume that the likelihood that two firms make acquaintance is inversely proportional to their geographical distance. In a second approximation one may consider the existence of roads and railways, which distort the space of acquaintances with respect to geographical space in the sense that two firms that are placed along the same road are more likely to make acquaintance than two firms placed at the same distance that are not directly connected by a road. In a third approximation one may consider the existence of institutions such as schools, clubs, churches and political parties that ease acquaintances between their members while hindering acquaintances between members of different institutions. It seems sensible to think that firms that are led by entrepreneurs that attended the same school, or the same church, or the same party, are more likely to be acquainted with one another.

In this model, complete ignorance of the actual structure of the acquaintance space is assumed. At the beginning of each simulation year 1975-97, firms are dropped randomly on the space of acquaintances. Subsequently, during each year 1975-97 firms move in the space of acquaintances, eventually forming chains of production.

Of all firms that can be found in the Prato district, middlemen are the most crucial. Middlemen arrange the operations of other firms. Thus, Middlemen are the only Pratese firms that have contacts with international buyers.

The history of each year (1975, 1976, etc.) is reconstructed by means of a large number of simulation steps. At the beginning of each year, the historically given number of each type of firm (Traders of Raw Materials, Rags Collectors, etc.) is placed randomly on the space of acquaintances. Middlemen stay fixed; all other firms move around randomly.

In particular, the Traders of Finished Products observe the surrounding space while they move around. As soon as they detect a middleman in their visual range, they move to it and place an order. In its turn, the Middleman starts to explore the acquaintance space around its position – i.e. its acquaintances – looking for firms that are able to carry out the production phases that yield the goods requested by the Trader of Finished Products. By default, all firms (except Middlemen) move around randomly in acquaintance space. However, as soon as they are reached by the command of a Middleman, they move immediately close to it and form a production chain – indeed, firms collaborating in a production chain are necessarily well acquainted with one another.

Appendix A illustrates these processes with the aid of flux diagrams. Figure (4) illustrates a snapshot of the model. Dots represent firms in the space of acquaintances. 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 one single Middleman.

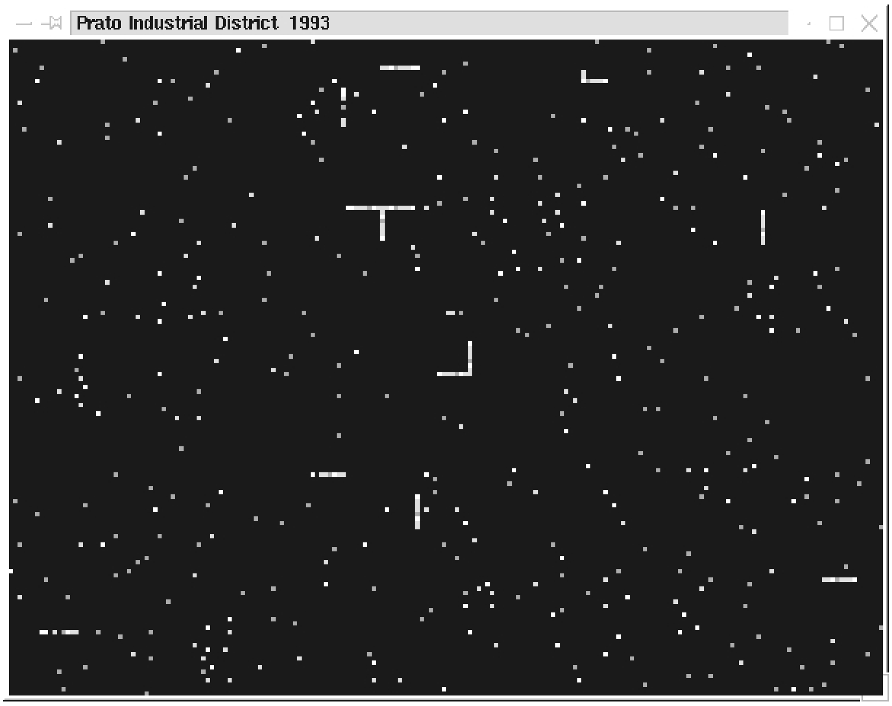

Figure 4
The space of acquaintance and the firms on it, at a particular step in the year 1993. Firms are colored dots. Lines are production chains. Production chains start with a Middleman. If a Middleman is arranging several production chains, several lines depart from it.

Middlemen cannot arrange firms in any order when they form a production chain. There are ten types of firms differing from one another according to the production phase that they carry out (Traders of Raw Materials, Rags Collectors, Carded Spinnings, Combed Spinnings, Warpers, Weavers, Dyeing Plants, Finishers, Traders of Finished Products and Middlemen). Technological requirements impose a sequencing on certain phases: Spinning must precede Warping, which must precede Weaving, which must precede Finishing operations. On the contrary, Dying may take place either before Spinning, or between Spinning and Warping, or between Weaving and Finishing (Avigdor 1961).

Furthermore, although all production chains yield the same final product – fabrics – they may employ different phases. In particular, spinning may be carded or combed. Carded spinning may make use of virgin wool or regenerated wool. In the first case, the Traders of

Raw Materials provide wool; in the second case, they provide rags and old clothes. Finally, certain semi-finished goods may be purchased by a supplier or they may be produced within the chain.

Figure (5) subsumes the above considerations in a general scheme of the production processes 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 be carried out at one of three different stages. 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 in the 1975-97 time interval.

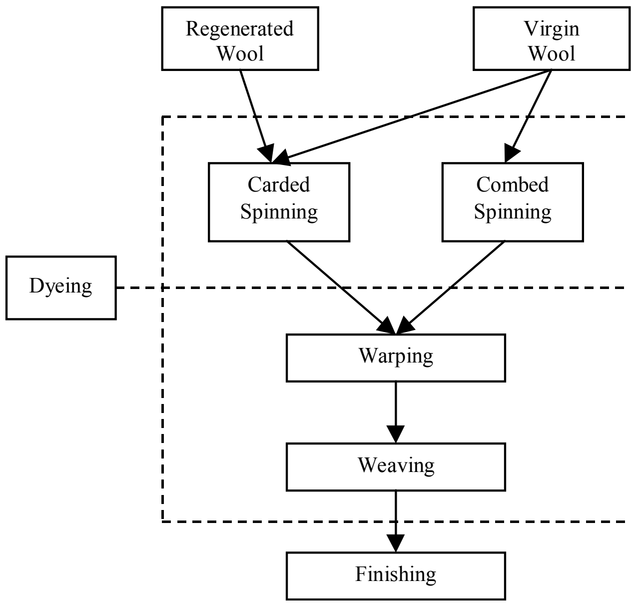

Figure 5
A scheme of the production processes to be found in Prato, rough enough to be considered constant over time. Dyeing can either take place before spinning, or before warping, or just before finishing operations. Spinning can be either carded or combed. Carded spinning may either make use of virgin wool or regenerated wool obtained from rags and old clothes. On the contrary, combed spinning necessarily requires virgin wool.

The technological constraints of figure (5) restrict the set of possibilities to the 11 production chains illustrated in figure (6). Figure (6) should be read top to bottom, from a Trader of Raw Materials (TRM) to a Trader of Finished Products (TFP). For instance, the leftmost production chain entails the following sequence: Trader of Raw Materials → Combed Spinning → Warper → Weaver → Dyeing Plant → Finisher → Trader of Raw Materials.

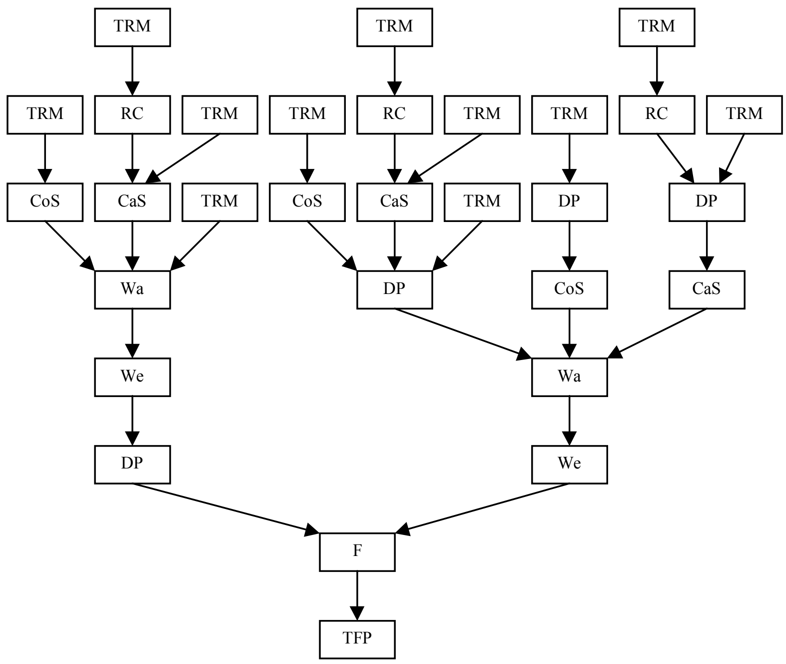

Figure 6
The eleven production chains that can be constructed with the ten given types of firms. Abbreviations are as follows: TRM = Trader Raw Materials; RC = Rags Collector; CaS = Carded Spinning; CoS = Combed Spinning; Wa = Warper; We = Weaver; DP = Dyeing Plant; F = Finisher; TFP = Trader Finished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

The choice of one among the 11 possible production chains illustrated in figure (6) depends on which firms are closest to the Middleman in its acquaintance space. As soon as a Middleman receives an order from a Trader of Finished Products, it starts to construct a production chain beginning from its end. In the terms of figure (6), it looks for a path bottom to top from a Trader of Finished Products to a Trader of Raw Materials.

A production chain starts when a Trader of Finished Products moves close to a Middleman and makes an order. The Middleman looks first of all for an agent that can be added to the Trader of Finished Products. According to figure (6), this must be a Finisher. Thus, the Middleman explores the surrounding acquaintance space. As soon as the Middleman finds a Finisher, it attaches the Finisher to the Trader of Finished Products. At this stage, the production chain is composed by two elements (TFP and F). According to figure (6), the Middleman may either attach a Weaver of a Dying Plant to the Finisher. Thus, it explores the surrounding acquaintance space looking for one of these firms. Whether it will attach a Weaver of a Dying Plant, depends on which firm it finds first. In other words, it depends on how many firms of each type are closest in its acquaintance space. This process continues along several bifurcations until a Trader of Raw Materials is found: at that point, a production chain has been completed.

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 to move randomly. However, if a Trader of Finished Products remains sufficiently close 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 move too far in the meantime, it is quite possible that the very same production chain will be reconstructed.

Thus, the model is path-dependent because production chains are chosen depending on the position of firms in acquaintance space. However, we shall focus on stable properties achieved by performing a large number of simulation steps for each year and by running the model with many different initial droppings of firms.

The number of steps in each year 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 from the names of the firms, I constructed a database that specifies in which phase of the production process a firm is specialized (warping, weaving, etc.).

[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 these firms have no employees, they do not appear in this database.

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, e.g., both in the list of dyeing plants and in the list of finishers.
2) Some large woolen mills have been included among the middlemen. One reason is that the model focuses on that part of their production that exceeds their productive capacity, for which they eventually contract other firms.

The size of firms may influence the formation of production chains if large firms process more orders than small firms, i.e. if large firms participate to a larger number of production chains. However, it is also possible that large firms are involved in the production of larger lots of fabrics. In this case, the two effects may balance out so the size of firms may have no influence on the formation of production chains.

Albeit no information on lot size is available, the size of the trucks employed by Pratese firms has been used as a proxy. Empirical research has shown that the average size of trucks increases from 1.0 - 2.5 t among the smallest firms to an average of 3.5 t among medium-sized firms and up to 5.0 – 9.0 t among the largest firms (Lattarulo 2001). These data suggest that we may assume that lot size is proportional to firm size and, consequently, that the size of firms does not influence the formation of production chains.

5. Robustness

Before exposing the results of the model it is in order to 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 firms are placed. With 2,000 to 3,000 simulated firms each year, a choice of parameters that yields sensible results is a variance of 10.0, a watching area of 100 pixels and a space of acquaintances of 300,000 pixels. Henceforth, these will be the *base values* of parameters.

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%. So 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.

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 the mean square difference between these two curves.

Table (1) illustrates the mean square difference from the curve at base values averaged over the 23 simulation years and the 11 production chains, where each curve was calculated on the mean of five simulations. The last row illustrates the mean square difference between two means of two different sets of five simulations at 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

	Mean Square Difference to curve with base values
Variance – 10%	0.000017
Variance + 10%	0.000013
Watching Area – 10%	0.000022
Watching Area + 10%	0.000023
Size of Space – 10%	0.000035
Size of Space + 10%	0.000022
Base Parameter Values	0.000022

According to table (1), variations of the parameters in a ±10% range generate errors that are of the same order of magnitude than the random variations exhibited by simulations with all parameters at base values. Thus, the model is very robust. 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 relative number of different production chains, the proportions of traffic between different geographical areas are obtained.

The province of Prato is composed by seven geographical areas, or communes: *Cantagallo*, *Carmignano*, *Montemurlo*, *Poggio a Caiano*, *Prato*, *Vaiano* and *Vernio*. The model reconstructs 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. Traffic within the more peripheral areas of *Carmignano*, *Poggio a Caiano* and *Vernio* could not be depicted because values were too small.

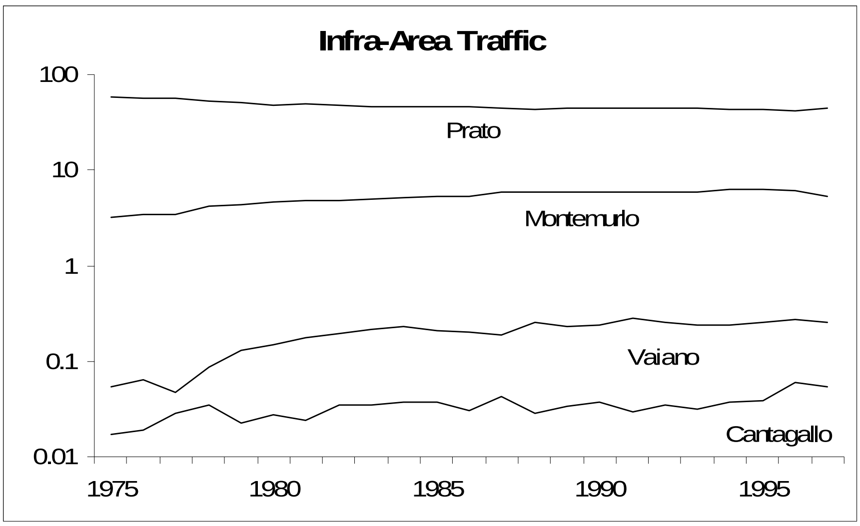

Figure 7
Percentages of wares traffic within *Prato*, *Montemurlo*, *Vaiano* and *Cantagallo* due to the textile industry, from 1975 to 1997. Averages over ten simulation runs at base parameter values.

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

Montemurlo, at a distance of just 6 from the town of *Prato* and in the process of forming a single urban 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 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 specialized firms in it. Development of the textile industry could be also achieved with, say, *Prato* specializing in trading and *Cantagallo* specializing in weaving, which would cause a large amount of traffic between these two areas but little traffic within them.

Figure (8) illustrates the shares of inter-area traffic in 1975 and 1997. The thickness of lines reflects the share of traffic in logarithmic scale.

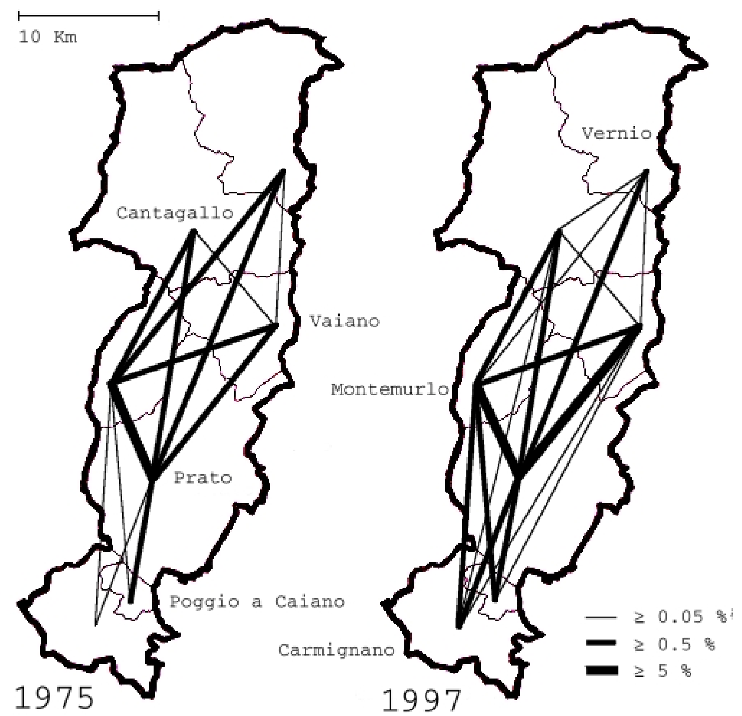

Figure 8
Traffic between the communes of the Prato province as percentages of total traffic. Simulation outcomes have been averaged over ten runs at base parameter values. Years 1975 (left) and 1997 (right).
The traffic within areas has not been depicted. The end points of segments do not reflect the 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%.

According to figure (8), the structure of traffic changed dramatically between 1975 and 1997. In 1975, *Prato* and *Montemurlo* monopolized any relationship the other areas had. In fact, on the left side of figure (8) 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 figure (8).

This development was caused by the specialization of some areas in one or a few phases of production. Thus, more inter-area traffic was needed in order to arrange the production chains. Figure (8) tells us that road traffic increased non-linearly with economic development, and that a substantial part of this increase took place along directions that do not pass through the city of Prato.

Retrospectively, a study commissioned by the public administration acknowledged that in the years 1970 – 1995 road traffic increased more than proportionately between small centers, whereas the road network was still centered on the city of Prato (Provincia di Prato 2003). However, gravitational models of the area have been unable to highlight this development because they lacked all details concerning the productive phase in which each particular firm was active (Lattarulo 2001). Thus, albeit agent-based models are still experimental, this technique may provide useful information for land use planning.

7. Conclusions

This article expounded agent-based modeling with respect to 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.

Data concerned (a) the number of firms for each productive phase in each year, and (b) the technological constraints between productive phases. The model simply read a set of 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 a 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 structure of road traffic from these data.

This procedure is not different from any other procedure 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 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, though it may be in the future.

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Appendix A

This appendix expounds the behavior 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).

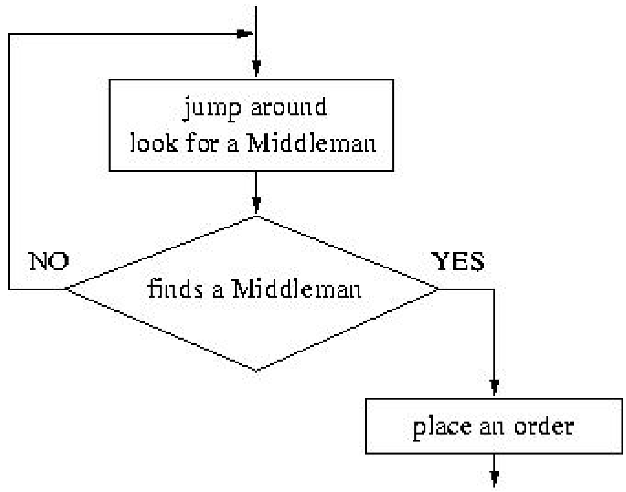

Figure A1
A Trader of Finished Products jumps around in acquaintance space, looks for a Middleman and, if it finds one, places an order.

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.

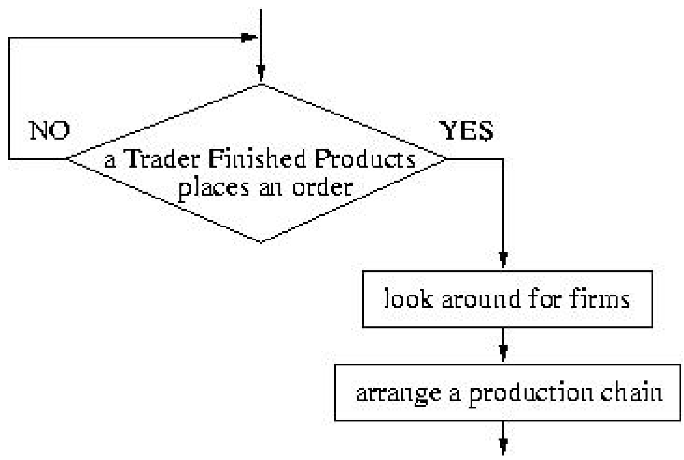

Figure A2
A Middleman receives an order, looks around for firms and arranges a production chain.

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

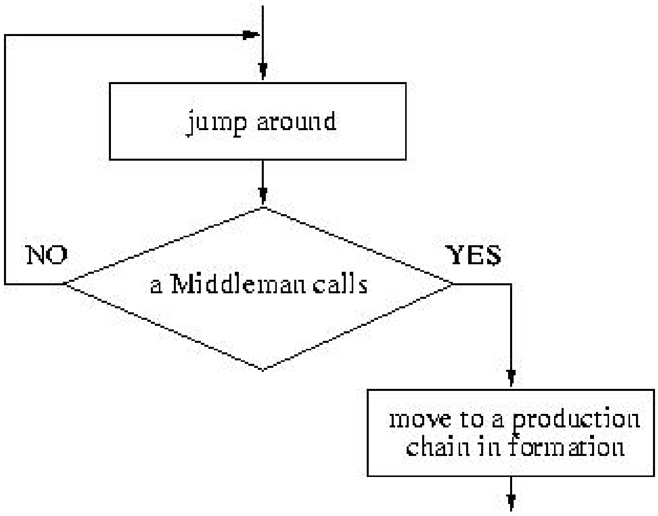

Figure A3
The other firms jump around in acquaintance space until a Middleman calls them to be part of a production chain.

The above sequences 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 [woolen 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 [carpets].
- **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 [woolen 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 fibers].
- **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 fibers] and generic sentences such as LAVORAZIONE TESSUTI [textiles processing].

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