Chapter 12
The Future of Urban Systems: Exploratory Models

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12.1 Introduction

Urban systems are complex systems, mainly because of the non-linear growth processes that lead to very unequal concentration of population and activities in towns and cities over historical time. We have seen in Chapters 7 and 8 of this book that supralinear scaling relationships were a distinctive feature of the structure and dynamics of urban systems. At the end of Chapter 8, we have shown a few examples of trajectories of the weight of individual cities relative to the system they form. These trajectories show inflexions, or even reversals in trend, alternating periods of urban growth and prosperity in cities when an innovation cycle is located there and (at least relative) decline and impoverishment when a former specialization cannot be so successful or even maintained in some urban locations. Because their sustainability depends mainly on the result of their interactions with other places, cities are permanently submitted to the necessity of transforming themselves to improve their position in the system of cities. The competition process for the attraction of innovation among cities, which ends in their unequal development, is a very complex one, because of the multiple interlocked networks that connect all city activities, including linkages between their inhabitants and artifacts. The spatial inter-urban patterns that are generated by so many different kinds of interaction flows and their effects on differential city growth and societal evolution show an incredible variety in shape and magnitude and cannot be predicted from simple analytical models. Only simulation models can give tractable representations for such complex dynamics (Sanders, Pumain, Mathian, Pace-Guérin, & Bura, 1997; Portugali, 2006).

In principle, the evolution of complex systems is unpredictable (Batty & Torrens, 2002). But simulation models, when correctly calibrated on past evolution, can help to explore issues among possible futures of these systems (Allen, 1997). This is especially possible in the case of urban systems, because their own structural dynamics is obviously slower than the succession of societal innovations that represent their main driving force, and, above all, because they exhibit a very strong *path*

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dependence in their evolution (Arthur, 1994). To succeed as an exploratory tool in predicting the future of a system of cities, a simulation model must satisfy at least two conditions. First, it has to be calibrated to properly represent the past dynamics of the system, since path dependence is a major property of the evolution of integrated urban systems; this raises the question of validation, which is a difficult and uncertain exercise in modeling by simulation, but much confidence can be gained when a generic model is able to reproduce, under reasonable parameterizations and initial conditions, either the effects of accidental exogenous events or the specific features of systems that are observed in different parts of the world. Second, when using the model as an exploratory tool for predicting the future, one has to include a number of probable changes in the demographic, political or technological context of the urban system, which may alter its further evolutionary path, and this will be done here in the case of the European urban system. Of course, this implies an abstract representation of the innovations, whose qualitative nature cannot in any case be predicted by any model.

To translate an urban evolutionary theory of urban systems (Pumain, 2000) into a simulation model, we designed a multi-agents system of interacting cities, in collaboration with the research group of Ferber (1995). The goal of this first prototype, called SIMPOP, was limited to the simulation of a few theoretical principles (Bura, Guérin-Pace, Mathian, Pumain, & Sanders, 1996). The model had a small number of cities (less than 400) and was calibrated roughly on the urban pattern of Southern France. The simulations demonstrated that one could reproduce the historical emergence of an urban hierarchy (over a period of two thousand years) from a set of rural villages (even from a uniform initial condition) *only* when interactions could occur between them (through a market and a competition for the acquisition of urban functions) and if new urban functions (i.e. innovations) were added more or less continuously during the process. The second version of this model, called SIMPOP2, which we present here, is adapted for a larger number of agents (about five thousand towns and cities in Europe). This new simulation tool is a more detailed and powerful multi-level multi-agents system. It is conceived as a generic model which can be applied to different levels of resolution in space and time and to a variety of geographical situations along with specific rules. We have derived four instantiations of this model, one called Eurosim[1] that aims at predicting the evolution of European large cities over the period 1950–2050, while the three others aim at exploring, by data-driven simulations, the past evolution of a variety of systems of cities in Europe (1300–2000), USA (1650–2000), and South Africa (1650–2000). One challenge is to understand which among the rules and parameters of the generic model have to be modified to represent the part of the urban dynamics that is particular to a specific time period or a region of the world (Fig. 12.1).

[1] The instantiation of this model was developed within the framework of another European research program called TiGrESS, (see http://www.tigress.ac/reports/final/eurosim.pdf and http://ec.europa.eu/research/environment/newsanddoc/article_2697_en.htm).

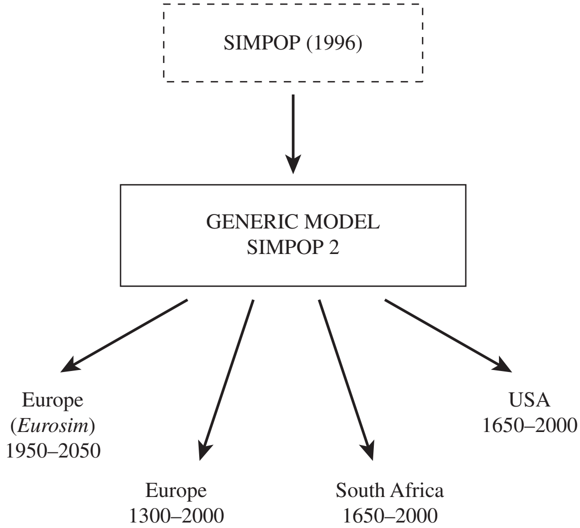


Fig. 12.1 Tree of SIMPOP generic and instantiated models

12.2 Urban Complexity and Multi-Agents Modeling

A variety of modeling techniques have been tried for simulating the dynamics of urban systems. Here, we recall only a few steps in this long history (Pumain, 1998). A precursor can be seen in the first Monte Carlo simulation of urban growth from rural and interurban migration flows (R. Morrill's method). A few attempts at using the formalism of catastrophe theory (Casti & Swain, 1975; Wilson, 1981) were not followed up. A first series of dynamic models were expressed as systems of non linear differential equations (Allen & Sanglier, 1979; White, 1978). These models described the evolution of state variables at a macro-level, the lower level interactions being summarized in mathematical relationships or in parameters. As interactions are non linear, the systems are not attracted towards a pre-determined equilibrium, a small change in the parameters of the model can modify the dynamic trajectory of the system and persist as a determinant of their further qualitative structure, according to a bifurcation. For instance, a small change in preference of consumers for large size and diversity of shops and a variation in the price of transportation can produce a spatial concentration of trade in a major urban center or its dispersion in a multitude of small centers. Even if some models made more explicit connections analytically between individual behavior and the resulting aggregated interactions (as for instance the synergetic model of interregional or interurban migrations first developed by Weidlich and Haag (1988) and applied to French cities evolution by Sanders (1992)), in practice there was very limited correspondence established with observations at a micro-level, since an "average" behavior was supposed to be representative of the individuals, and the applications were conducted with statistics on aggregated flows. Conversely, micro-simulation models integrated many details about the behavior and familial or professional career of individuals, but did not pay so much attention to the evolution of the resulting structures at the macro level (Clarke, 1996; Holm & Sanders, 2007).

Compared to these earlier attempts to achieve self-organization in urban system models, the actual notion of emergent properties refers to a more explicit modeling of interactions, usually in agent based models or in multi-agent systems (Ferber, 1995). Multi-agents systems (MAS) are especially useful as simulation tools for modeling dynamics, when it is essentially explained by the heterogeneity of individual features and their interaction (Sanders, 2007). They enable the modeler to associate qualitative and quantitative rules and to integrate several levels of organization, diverse time scales, and dynamic relationships. They appear as a reasonably promising technique for simulating geographic worlds, mainly because of their ability to consider the environment of a system, their acceptance of a wide conceptual diversity of agents (allowing for multi-level analysis) and their flexibility regarding interaction rules, especially in spatial relationships. Multi-agents systems are much more flexible than differential equations for simulating spatial and evolving interactions, including quantitative and qualitative effects. Through the definition of rules at the individual level, they can reproduce the circulation of information between cognitive and decision making agents. They simulate, at the upper level, the emergence of collective or aggregated structures that can be tested statistically. The rules can be adapted for varying space and time scales of interaction under the course of history.

12.3 Ontology of the Generic Model

Before demonstrating how it can be used to explore a variety of urban evolutions, we describe briefly the general architecture and components of the SIMPOP model, that is, in the computer scientist vocabulary, its "ontology." We have identified, in Chapter 6 of this book, a number of stylized facts that are common to all urban systems. They characterize, at the macro level of urban systems, major structural features and evolutionary processes (as size differentiation, functional diversity, and distributed growth) that emerge from the interurban competitive interactions. A model should simulate how the cities' interactions produce these emergent properties. But drastic simplifications are required. Even if the computer's capacities today allow simulations of the individual daily moves of inhabitants in a city with population of two million (for instance, Eubank et al., 2004), it would be impossible (and probably irrelevant) to represent, at the same detailed individual level, all the interactions between the 320 millions of Europe's urban citizens distributed among 5,000 different urban agglomerations over several decades! Each model is an abstraction based on generalization. Since multi-agents modeling authorize a rather direct representation of a conceptual model, we decided to make three major abstractions for SIMPOP over the finest grained scale: first, we consider interactions between cities only, not between individuals, so that cities are considered as the "agents"; second, we select among all urban activities those that have a specific role in each city's dynamics, i.e., their specialized functions, as main city attributes;

third, we retain only, among all real exchange flows that are generated by these functions, the relations that may create asymmetries, that is, "second order" interactions (Pumain, Bretagnolle, & Glisse, 2006).

12.3.1 The System of Cities and its Environment

We define urban systems as subsets of cities that can evolve through their interactions under a few external conditions. The systems we consider are never totally closed, nor can they evolve in a fully endogenous way. They correspond, in geographical theory, to subsets of cities that are submitted to the same general constraints (whatever they are, political or legal control, demographic and economic trends, cultural features, or constraints stemming from the use of the same limited amount of resources – geographers would call this coherent envelope a "territory") and whose evolutions are interdependent, because of the many connections that link cities together. In the real world, a relevant frame for delineating systems of cities can be a national state (remaining roughly but widely valid during the last two centuries), but it may encompass a continent, or even the whole world in the case of certain "global" or specialized cities. The concrete systems of cities that we have chosen in our application belong to both types, continental or national (Europe, USA and South Africa).

The concept of environment in multi-agents modeling defines the medium of interactions between agents, which corresponds, in our case, to the location of cities (as they are immobile agents) and the societal conditions allowing them to communicate. This backcloth for inter-urban interactions is an evolutionary space, measured in space-time terms, because of progresses in communication techniques. We also describe a few more contextual exogenous components that cannot be generated through the interactions between cities but are necessary for the simulations. At first, there is a subset of elements that define the *initial conditions*, including a "map" locating the cities that are part of the system or that will be activated during its evolution, and their corresponding initial attribute values (especially a lognormal distribution of city sizes). This map can be a random pattern, generated by a stochastic process, or an observed set of geographical locations (Fig. 12.2). The first SIMPOP model focused on the emergence of a hierarchical system of cities and on the progressive structuring of the urban system according to size, functions and spatial proximities, starting from an isotropic spatial organization. The initial situation corresponded then to the almost uniform distribution of settlement pattern that is classically associated with a homogenous agrarian society. For the simulations with SIMPOP2, a larger diversity of initial conditions are necessary, on the one hand to start the simulation from any observed urban pattern, and, on the other hand, to test systematically the impact of different theoretical initial situations. As the simulations are made over longer historical periods, alternative theoretical patterns can also be used to control the possible effects of a geographical and political configuration on the general urban dynamics. Figure 12.2, for instance, represents

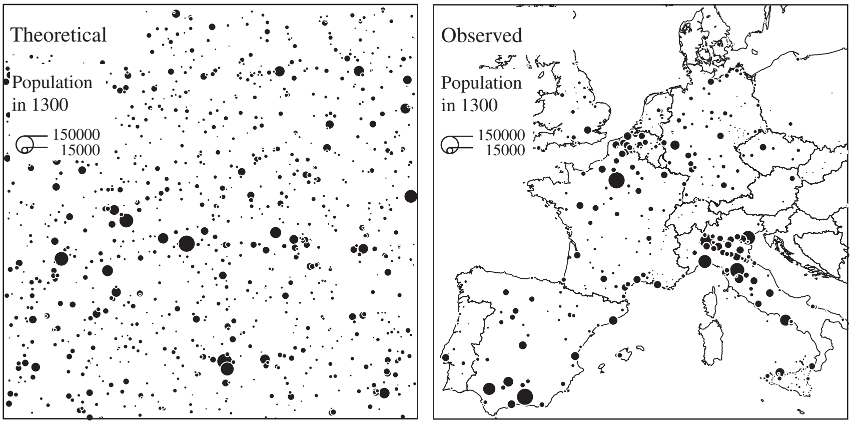


Fig. 12.2 Examples of initial urban patterns: theoretical and observed

two initial patterns for Europe in 1300: one corresponds to the observed situation; the other to a fictitious spatial distribution (a triangular grid) reproducing the numeric properties of the European urban system at that date. Population sizes are distributed spatially in a random way according to a lognormal distribution of same mean and standard deviation as observed. In the case of the Eurosim model, which represents the dynamics of the European system of cities for the period 1950–2050, the initial situation, urban Europe in 1950, corresponds to an observed and already well-shaped urban system, which has attained some maturity after a millennium of urban development. In that case, the inherited *form* of the urban system influences its future evolution, but new elements and configurations can emerge as a result of the way the cities catch (or not) new innovations, and the model is used to simulate the corresponding changes in cities' relative positions.

Another subset of exogenous data that complete the contextual "environment" of our system of cities are the number and type of the entities called "urban functions" (see below, Table 12.1) that represent innovation bundles (for production or services) with their historical date of appearance in the evolution of the system, and their associated attribute values. A third subset of external elements are parameters that describe the general demographic or economic growth of the society and the period under consideration. These variable parameters (in very limited number) are essential for calibrating the model; they have to be adapted to the historical and geographical context of each specific instantiation.

12.3.2 Cities as Collective Agents

In our epistemological framework, the city is not considered as a collection of individuals and enterprises whose simple aggregation would permit us to understand and reproduce the city's evolution. Rather, the city is seen as a complex entity that

Table 12.1 Urban functions and their dates of activation in SIMPOP2's instantiated models

		Eurosim: Europe (1950–2000)	Europe (1300–2000)	USA (1650–2000)	South Africa (1650–2000)
Central functions (proximity principle)	Central 1		1300	1650	1650
	Central 2		1300	1800	1800
	Central 3	1950	1800	1850	1900
	Central 4	1950	1900	1900	1960
Territorial functions (political principle)	Territorial 1 (regional capital)	1950	1300	1800	1900
	Territorial 2 (Capital)	1950 (1990 for Berlin)	1500 15 cities	1800 1 city	1900 1 city
Specialized functions (Network principle)	Long distance trade		1300	1650 (east); 1860 (west)	1650
	Manufacturing 1 (Industrial Revolution)	1950	1800 Industrial Revolution	1830 Industrial Revolution	1860 Industry gold/diamond
	Manufacturing 2 (Electricity, automobile)	1950	1900 Electricity-automobile	1880 Oil, electricity-automobile	1930 Electricity-automobile
	Technopoles (NTIC)	1st wave in 1950; 2nd wave in 2000	1950	1940	1960
	Finance	1950			
	Tourism	1950			
	Hub (transport)	1950			
	NBIC	1990			

makes sense as a whole, characterized by its attributes and following some rules of evolution. This conception has led us to adopt a unique approach in the field of multi-agents systems (MAS) where most of the applications concerning social sciences are developed at the level of the individuals, with the idea of analyzing and understanding the structures that emerge at a higher level of observation from the interactions between their actions. In this respect, we agree with Openshaw (1997) that the lowest level of observation is not always the best one from a conceptual point of view. It is also important to state that there are not only two levels of interest, that of the individuals (micro-level) and that of the society (macro-level), but there are a whole set of intermediate levels of interest, including the cities.

While identifying a city as agent, our hypothesis is that the grounds for differentiated growth are better understood at that level than at the level of the households or of the individual political and economic actors. Of course the decision-making processes of each actor in the city has an impact on the city's development, but whatever this impact, it is *limited* compared to mechanisms of change, which obey meso-geographical regularities. Indeed, individuals' actions are of little weight with respect to a city's trajectory in the long run, whose trend is not very sensitive to the diversity of individual intentions and decisions. These meso-geographical laws determine the context, in terms of possibilities and constraints, in which actors of different kinds and levels make their decisions. They determine the "bounds" of the possible future for a city, given its characteristics (size, accessibility, socio-economic profile, specialization. . .). These bounds can be interpreted as local attractors in the dynamic trajectory of a single city. The decisions of political or economic actors thus influence the direction of the trajectory towards one "bound" or the other. In other words, the meso-level dynamics give an "interval of plausibility," and the urban actors' decisions and actions determine *where* in this "interval" the change will occur.

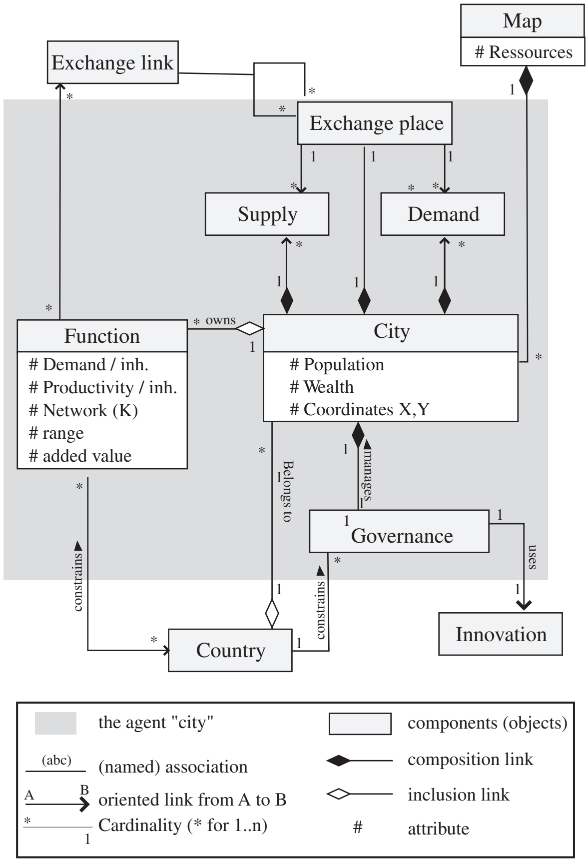
So the elementary entities of the model are cities, each represented by an "agent" in the terminology of multi-agent systems. This agent has a certain degree of autonomy as far as its decision making process is concerned; it handles information about itself, about the properties of the cities with which it is interacting, and the rules of evolution. It is able to communicate (through a set of interaction patterns called, in technical terms, a protocol of communication) with the agents representing the other cities. Through a collective entity called "governance" that represents the decisional capacity of urban actors, it acts not only as a reactive agent but can develop different types of strategies, including a more or less risky approach to the acquisition of new functions (investment). Urban functions are introduced exogenously during the simulation at given dates corresponding to the major innovation cycles (in an entity called "innovation," which is part of the context of the urban system). They can be attributed to cities in a passive way, according to a set of criteria that determine their allocation, or through the governance entity according to strategies of imitation (of neighboring or well-connected cities or cities that are similar in size or economic profile) or strategies oriented toward risk and innovation.

As our aim is to model the structure that emerges from the interactions between cities, our hypothesis is that the *interactions* between cities are the driving force in the evolution, and they determine the future of each city as well as the evolution of the macroscopic properties of the system of cities. These interactions stem from migration flows, commercial trade, information flows, knowledge exchange, etc. They determine how innovations will spread throughout the system. The hypothesis is that this is relevant for different types of territories and at different periods of time, for which towns and cities exist. That justifies the elaboration of a generic model, based on this conceptual framework and containing the common rules of evolution of towns and cities embedded in a system of cities (Fig. 12.3).

12.3.3 Main Attributes are Urban Functions

The simplest attribute of a city is a *location*, i.e. its geographical site. In our model, a map (see Fig. 12.3) is part of the initial condition, including many possible locations (given by two coordinates) for cities. During the simulation, new cities are activated

Fig. 12.3 Representation of SIMPOP2's ontology



at a rate corresponding to historical observations. The rules for this activation can vary according to the historical type of settlement in a country: in old urban systems, new cities arise randomly between the existing ones; while in countries of the new world, cities are generated along frontier lines. Their *relative location*, that allows cities to be more or less easily connected to others, may introduce a potential differentiation in their evolution. Accessible environmental resources, such as coast lines or natural corridors (allowing for the acquisition of trade functions) or mineral deposit zones that are also located on this map as exogenous information, are also part of the city attributes and can be useful for introducing the specific effects of resource-depending innovations.

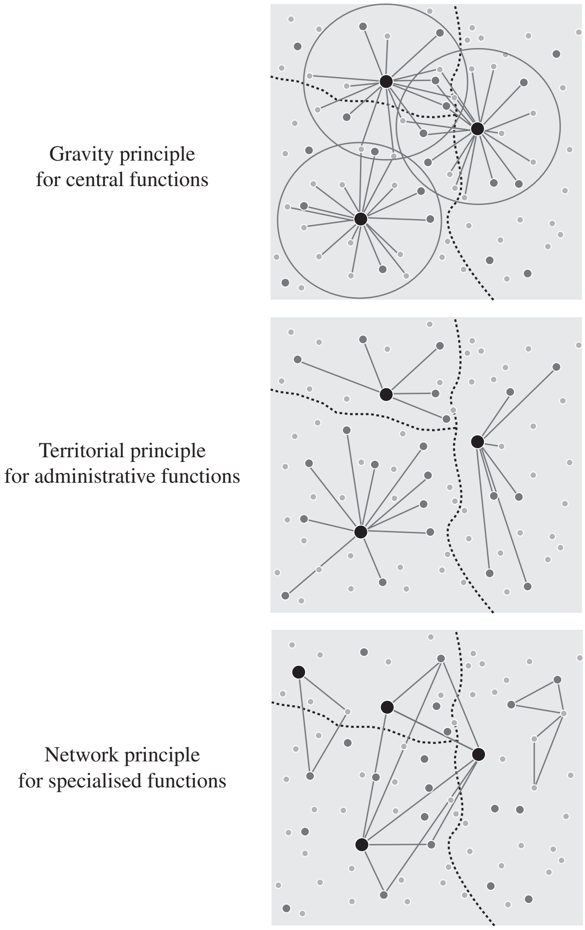
Each city is characterized on the one hand by its *population* and its *wealth*, which constitute the main state variables of the model; and, on the other hand, by its *functions* and the *distribution of its labor force* according to the associated economic activities. Two synthetic attributes, the *total population size* and the *accumulated wealth*, represent the strength of each city-agent in the system of cities. They summarize the past ability of the city to attract population and benefit from its exchanges with other cities. These attributes depend, modulo stochastic factors, on another set of attributes, which is the portfolio of functions that define the capacity of action for each city in the system. An urban function represents the subset of urban activities which may generate asymmetries in the interactions between a city and other cities. The principle is taken from *economic base theory*: the potential of growth of a city, i.e. its ability to attract new population and new activities, depends on its ability to produce and to valorize "fundamental" productions or services that are export-oriented.[2] The core of the SIMPOP2 model concerns the formalization of the exchange market between cities. In short, the growth of each city will depend on the success of its exchanges. The type and level of function can evolve through time depending on the ability of the city to adopt innovations and to become attractive for some dynamic and leading activities.

Three families of functions are distinguished, each one corresponding to a different principle of spatial interaction (Fig. 12.4 and Table 12.1):

1. *The central functions* generate interactions according to a *principle of proximity* (or *gravity principle)*, following a spatial interaction model that is currently described by equations similar to Newton's formula and included in Christaller's central place theory (Christaller, 1933). They include the most classical urban activities – commercial activities as well as services and some manufacturing industries, whose production is intended for a regional market, i.e. neighboring towns and cities. The spatial interaction principle is the same whatever the spatio-temporal context, but the associated ranges of influence vary according to this context. More specifically, there are four possible levels of central functions (central 1–4) that emerge successively during historical times; they are hierarchized according to the complexity of the services they perform and to the spatial range of their influence. Figure 12.4A illustrates the spatial operating of this family of functions and how the competition between cities occurs through the overlapping of their zones of influence.
2. *The territorial functions* include the administrative activities that operate within the frame of political or administrative boundaries. They include two levels, the specific functions of the capital of a national territory or that of a regional capital (Fig. 12.4B). The administrative services that are produced supply the demand of all cities and towns of the corresponding region or country only: there is no competition across the boundaries.
3. *The network functions* consist of very specialized activities that were created by major economic cycles with a large range of trade; their development depends on the relative position of the city in a system of specialized trading relationships (Fig. 12.4C) rather than on spatial proximities. These functions are of different kinds, according to the main economic cycles that created major urban specialization, as described in Chapter 6, and their operation obeys different rules depending on the cycle to which they belong. These rules express the probability

[2] Fundamental activities are classically opposed to induced activities, which are oriented towards the local urban or regional market.

Fig. 12.4 Three types of spatial interactions



of different pairs of cities to be connected through trade, given their respective socio-economic profile (relations of complementarities for example, see below in Table 12.4).

The list of urban functions may vary according to the instantiated model. For instance, Eurosim[3] establishes more categories among recent urban functions (Tourism, Hub, Finance and NBIC), while ignoring maritime trade, which remain essential for the simulation of European urban system over more ancient periods of time. It also has less distinct levels of central functions, and uses NBIC (converging nano, bio, information and cognition technologies) as the expected leading innovation cycle for exploring the next decades of urban specialization.

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[3] Knowledge about the functional evolution of European cities was used to control the hypotheses investigated (Cattan, Pumain, Rozenblat, & Saint-Julien, 1994; Cicille & Rozenblat, 2004).

12.3.4 Variables and Parameters

The aim of a simulation can be better understood by identifying essential variables of the model (Table 12.2). As seen above, the *state variables* of the model are the population, wealth of cities, and amount of labor force in each of their functions. They are computed at the city level and later aggregated to the level of the system of cities as a whole when the simulations are analyzed. But, other parameters have to be introduced to characterize the evolutionary context of urban dynamics. These *contextual variables* correspond to a higher level of interactions compared to those simulated in the model. They are given exogenously. They enable a calibration of the model on observed historical data. They define a mean growth rate for population and wealth (or economic product) and, for each type of function, their date of emergence, productivity level, demand level, and increase in value (profit gained from trade in addition to the actual amount exchanged). Productivity and demand could not always be retrieved from actual data and were sometimes first estimated and then tuned by calibration.

Intermediate variables are computed during the simulation; they characterize the dynamics of trade between cities (as unsold goods, or size of the customer network) – see Section 12.4, below.

Key parameters are decisive for calibrating the model. They keep the same value for every city but can evolve through time. Their value cannot be observed and has to be determined by trial and error, but has to remain in some domain of validity (for instance corresponding to a plausible historical succession of values or a logical cross-comparison of urban functions). This is a rather long and difficult process, since the effects of these parameters interact with one another. The simulations enable the modeler to check the sensitivity of the model to the variations

Table 12.2 Main variables and parameters in SIMPOP2

Category	Parameters
State variables	Population, Wealth, Labor force by urban function
Contextual variables (exogenously defined for each urban system)	Population and wealth: mean growth rates Date of emergence of each function Productivity, demand, added value, for each function
Intermediate variables (endogenous)	Unsold goods, Unsatisfied demand Size of the networks
Key parameters (calibrated)	Range of exchanges associated to the different functions Size of exchange networks for specialized cities Attraction level on labor force % of valuable customers Returns from the market on urban growth Barrier effects of boundaries

of these parameters and to choose the values that give the best fit to observed data. Six parameters are used, among which three (described below) modulate the city population growth according to the results of exchanges through urban functions (Table 12.2). The other three key parameters (range of exchanges, size of exchange networks and barrier effects) will be described below with the rules that use them.

1. *Share of growth not generated by the model*. This parameter helps modulate the mean growth rate that is introduced in the model as an exogenous demographic trend and that cannot be injected in the model as such, since interactions between cities also generate a significant share of urban growth. Remember that this mean growth rate that is allocated to each city represents an exogenous conjuncture, which reflects the historical trends in demographic evolution.
2. *Return from market on demographic growth*. This is a feedback effect from economy on demography, which is linked to the balance of exchanges of cities for each function. This balance leads to a wealth increase or decrease. This parameter varies according to the profit that can be generated by each urban function. It enters in the equation where the wealth of cities is computed at the end of a cycle of exchange and influences the city's demographic growth (Table 12.5, Equation 12.3).
3. *Attraction on labor force*. Agents can adapt their labor force to the economic context that is perceived by cities through their acquaintances, by increasing or diminishing the number of employed in a given function. This translates to population growth or decline. When demand exeeds supply, this labor force is increased; while, on the contrary, it is decreased if there are unsold goods and services.

12.4 Rules of the Model

The various instantiations of the SIMPOP2 model share a number of similarities that define the SIMPOP2 paradigm (see the generic model introduced in Sections 12.1 and 12.2). In addition, they specialize to address a specific problem or context. They each deal with a defined case study as well as precise objectives. We describe here the main rules that are given to Eurosim and SIMPOP2 Europe and relate them to the scopes of the two models as well as the scope of the overall SIMPOP2 paradigm.

12.4.1 Time and Interactions

Due to the computational nature of Multi-Agent Based Simulation, the evolution of state variables is, by nature, discrete. Though, Multi-Agent Systems rely on two scheduling techniques (Michel, Ferber, & Gutknecht, 2001; Ramat, 2007):[4]

[4] The first technique is discrete time: the simulation is divided into iterations within each the agents that are activated. The scheduler is like a clock that can translate the virtual time of the model, the

SIMPOP2 uses first a discrete time approach and then an event based one to model the numerous round trips of the interactions occurring within a time step. The flow of time is divided according to the temporal resolution of the models. For Eurosim, which covers periods from 1950 to 2050, iteration is made each year. For SIMPOP2 Europe, which runs over a larger period, from 1300 to 2000, an iteration represents 10 years. This is a modeling choice that enables simple comparisons between the simulation results and observations from the real world. Also, the more the system of cities advances in time, the more the interactions become overwhelming. It is then reasonable to introduce more iterations, which can possibly capture quicker transformations of the system.

As explained in Section 12.1, the interactions are the driving force of the model. The model assumes that, during each iteration, the city-agents fulfill their trade exchanges to the end. That is, trade occurs till no more can be done (the round trip effect mentioned previously). This assumption is reasonable, considering the length of the corresponding period in real time. Within an iteration, the agents are then enabled to trade in a recursive fashion. This can be interpreted as an event driven process: an unsold supply tries to meet an unsatisfied demand and vice-versa.

12.4.2 Detail of an Iteration

Figure 12.5 gives a synthetic representation of an iteration in SIMPOP2 that we shall now detail. At first, the amounts produced by each city and the demand expressed by its population are computed. This is made by using contextual parameters that define the productivity and demand at individual levels for each type of goods and services provided by each urban function at a given time.

The *computation of the trade networks* is then made for each urban function, and may vary according to the specific models. Different constraints are imposed on the topology of the trade networks according to the three spatial types of interactions (Fig. 12.4). The transportation improvements are visible, for the SIMPOP2 Europe model, in the central functions that appear one after another in the system (Table 12.1). They are also represented in the values of a parameter that expresses the maximal possible range for trade from any city (evolving through time and according to city size). Moreover, we introduce two key parameters that help estimate the potential market of a city by fixing a maximum size to trade networks and by allocating a proportion of trade devoted to previous customers, the remaining part being reallocated randomly each time. The values taken by these parameters are important for regulating the stability of the model, which is highly sensitive to them.

Table 12.3 summarizes a few rules for generating possible trade relationships between cities located at different distances or having different demands according to the functions they have.

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iterations, to real time. The second technique is event based: the scheduler executes events one after another given their chronological order (events possess a timestamp). The events and their order can be known from the beginning or they can be created by the agents during the simulation.

Fig. 12.5 Steps of an iteration

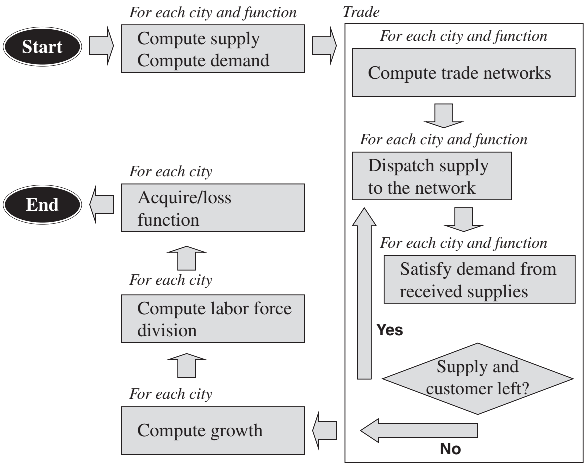

Table 12.3 Cities involved in trade networks by urban function

Urban Function	Type	SIMPOP2 Europe	Eurosim
Central1	Intern	–	–
Central2	Proximity	<70km	From 150 to 250 km
Central3	Proximity	<80km	n/a
Central4	Proximity	Before 1950, within 100km; 150 km after	n/a
Regional capital	Territory	–	n/a
Capital	Territory	–	–
Long distance trade	Network	Central 2 cities*	n/a
Manufacturing I	Network	Manufacturing I cities*	Manufacturing I or II
Manufacturing II	Network	Manufacturing cities*	Manufacturing cities
Tourism1	Network	n/a	All cities within the country and neighbouring countries
Tourism2	Network	n/a	Among largest and richest cities
Hub (transport)	Network	n/a	Largest cities
International Finance	Network	n/a	ManufacturingII, Tourism2, Hub, Technopole, NBIC or Capital cities
Technopole	Network	Central 4 or Manufacturing II cities*	Manufacturing II, techno, NBIC, capital or largest cities
NBIC	Network	n/a	NBIC and cities above one million of inhabitants

*there is a range constraint as well, but after 1800 almost all Europe is covered

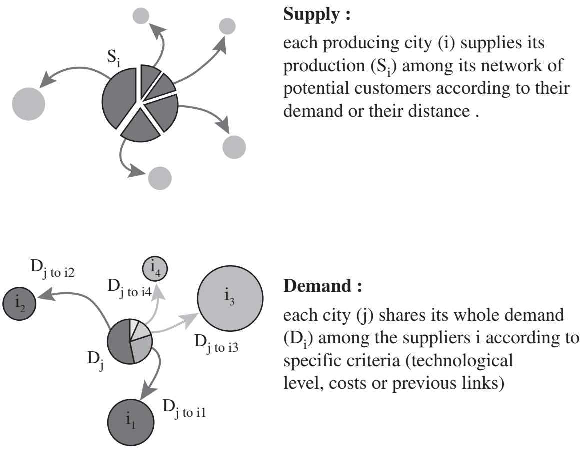

Fig. 12.6 Rules of market exchanges

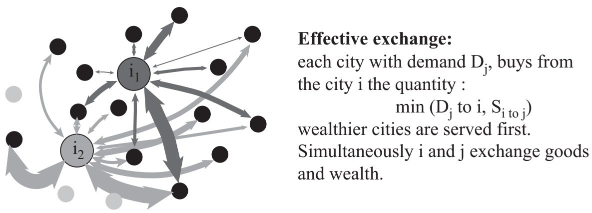

Fig. 12.7 Interactions resulting from market exchange. Line thickness indicates quantity

The resolution of trade networks involves a supply dispatching from the producers to its network of consumers and the actual “purchase.” Figure 12.6 shows how market exchanges are managed. The preference for Eurosim is based on low and high costs to be economically consistent. The wealth per inhabitant is used as a proxy for the level of wages and production costs. SIMPOP2 Europe considers distance and connectivity between seller and buyer. This is a trade off to consider both the impact of transportation in early ages and globalization at later stages.

The trades can lead to a complex topology. The networks can overlap and, thus, competition occurs. Figure 12.7 gives an example of two cities that try to sell the same production of a Eurosim urban function. Round trips are then necessary to dispatch the productions, because a perfect first match between supply and demand for a particular “supplier” or a particular “buyer” is unlikely.

At the end of the exchange process, the growth of the city-agent is computed by taking into account three elements, as detailed in Table 12.4. First, a positive or negative feedback from the trade exchanges is given, depending on their success (measured by unsold products or unsatisfied demand). This is translated into an *attraction on labor force* which increases or decreases the amount of employees within the corresponding urban function Second, the demographic growth impulse given to the city from the general *demographic trend* of the country is computed. Third, a positive feedback is made from the wealth to the population growth through the *market return parameter*: urban functions generating high added values will bring a greater benefit to the city.

Table 12.4 Assessment of economical exchanges and computation of population variation at the end of an iteration

Total population variation at the end of an iteration
The total population at t + 1 is function of 3 components:

$$P_i^{t+1} = (P_i^t + \Delta^1 P_i^t)^*(1 + \partial_1 + \partial_2)$$

(1) Evaluation of labor force attractivity for each urban function k of city i:
First the variation of labor force between t and $t + 1$ for the sector k is evaluated by $P_{ik}^{t\to t+1} = s_{ik}^t PotM_{ik}^t$, where $P_{ik}^{t\to t+1}$ designs the variation of workers in sector k, based on the potential of the trade network of this sector for the city i (PotMtik). The potential compares the demand of customers for the sector k, to the supply of the city at time t after the trading process. If there are unsold goods, the potential will be negative, conversely if there is unsatisfied demand, it will be positive.
s_{ik}^t is a parameter whose value follows a normal distribution $N(m_s\sigma_s)$. For the short term simulations it may be interpreted as the "speed of adjustment."
The variation of total active population due to the market adjustment is then given by:

$$\Delta^1 P_i^t = \sum_k P_{ik}^{t\to t+1} \tag{12.1}$$

(2) Demographic trend:
The second part of the evolution depends on the general demographic trend weighted by systemic effects:

$$\partial_1 = \alpha^{t*} G_h^t \tag{12.2}$$

where G_h^t is the global demographic trend observed at time t in the region h and α^t a parameter that evolves over time between 0 and 1. This global trend may vary over regions (according to differences in stages of demographic transition). α^t represents the share of growth that is not generated by the model.
(3) Market returns:
The third part of the evolution of the population depends on the city wealth increase:

$$\partial_2 = \beta^{t*}\ f(\Delta w_i^t) \tag{12.3}$$

w_i^t is the wealth of city i at time t, $f(\Delta w_i^t)$ estimates the balance of wealth of the city i between t and $t + 1$, β^t is the weight given to this third component of the population variation at time t. If there is no wealth increase, there is no effect of market return on city population growth.

When growth is computed, the city-agents update their labor force. The increase or decrease is made according to the intermediate variation determined in step 1 of the growth computation (Equation 12.1 in Table 12.4). A final value is set after respecting the constraint that the total active population represents about 45% of the total population (by normalizing). The city-agents can lose one urban function when their labor force reaches 0.

Regarding the rules for acquiring new urban function, they are given exogenously and may vary according to the model. In the Eurosim model, given the relatively short period of time, the allocation of functions is made *a priori* within

Table 12.5 Rules for the adoption of new urban functions in the SIMPOP2 Europe model

Urban function	Dates	Emerges among:
Central 1	1300	–
Central 2	1300	largest Central 1
Central 3	1800	largest Central 2
Central 4	1900	largest Central 3
Regional capital	1300	largest Central 2, minimum spacing
Capital	1500	largest Chieftown, minimum spacing
Long distance trade	1300–1800	largest Central 2, preferential locations (zones)
Manufacturing 1	1800	largest Central 2 or preferential locations
Manufacturing 2	1900	Central 3 or manufacturing 1
Technopole	1950	Central 4 or manufacturing 2

the initial situation in 1950 and the locations of the latest emerging function (corresponding to the NBIC specialization) are selected from this date, even if activated in 2000 only. The SIMPOP2 Europe model uses rules that are summarized in Table 12.5. The conditions that are requested reflect the most frequently observed transition in urban specializations as they were observed in the history of European cities.

12.5 A Multiscalar Method of Validation

In our simulation model, there is no optimizing constraint, and the evolution is open as in any exploratory simulation tool. However, we need some validation procedure to assess both its ability to reproduce past observations reasonably well or to evaluate the magnitude of deviations between a diversity of future scenarios.

To calibrate and validate the model, as well as to valorize the different results of the simulations, a multiscalar tool of "simulation data outputs mining" has been developed. The main objective is to test the coherence of the rules introduced in the model, its ability to produce trajectories that are realistic according to observations, and to get an insight in its sensitivity to initial conditions and parameter variations. But the potential outputs of the simulations represent a huge amount of data. For instance, in the case of Eurosim, the output for one simulation relates to 5,000 towns and cities, 100 time steps, 13 functions, and all interactions associated to communications and exchanges between the cities. Therefore a visualization and exploration tool for analyzing the outputs has been developed. This method investigates a data hypercube including three conceptual dimensions: time, state variables, and space, including interaction flows and multi-level organization. In addition, the calibration process includes methods for identifying which parameters influence the dynamics of the quantities and which influence the structures themselves (as urban hierarchies or configuration of exchange networks).

Thus, rather than computing only one objective function that would be a one-dimensional summary of the simulated values, we define a multidimensional framework for evaluating the simulation. This framework includes measurements on the structural features of the urban systems: hierarchical, spatial, and functional, and this is evaluated at different scales. Different investigations are also introduced according to outputs: for instance, some, as population, wealth, labor force, are of interest from a thematic point of view while others are only used to check the coherence of the model and to help calibrating it.

The outputs are highlighted and summarized according to three entries corresponding to different geographical levels: the macro-level (European urban system for Eurosim or SIMPOP2-Europe) is the aggregate level; the local level concerns the cities themselves; between these two extremes, there are a series of intermediate results and outputs, corresponding to different kinds of geographical aggregation of the results from the city level:

- territorial: a regionalization can be defined, such as Eastern and Western regions for Europe, or national states;
- hierarchical: grouping cities by size class can help in detecting if there is a systematic size effect in the cities' evolution; and
- functional: grouping cities with the same specializations or with the same number of specializations to illustrate the effect of different functional levels on differential growth.

The number of variables to be represented, the use of different aggregations, and the use of different methodological filters produce a large amount of outputs. We use the complementarities between different ways of analyzing the outputs to get a complete overview of the different states of the urban system during the successive periods. This also enables a multi-dimensional comparison of the different simulations, which then facilitate the calibration of the model.

The outputs are analyzed through a series of methodological filters, as shown in Fig. 12.8. Thus, a standard report will include the description of the three geographical levels.

The macro level (global urban system) is described through:

- global trajectories: population, wealth, variation rates of population and wealth, repartition of the labor force by activity sectors;
- hierarchical structure: rank size representation and modeling over time for population and wealth, primacy evolution; and
- spatial structure: global maps.

Intermediate levels (regions, subgroups of specialized cities) are analyzed with:

- demographical trends by regions, by family of specialized cities;
- evolution of the global exchanges by sector of activities; and
- decomposition of the different components of supply and demand by sector of activities.

And the local levels (cities) are illustrated through:

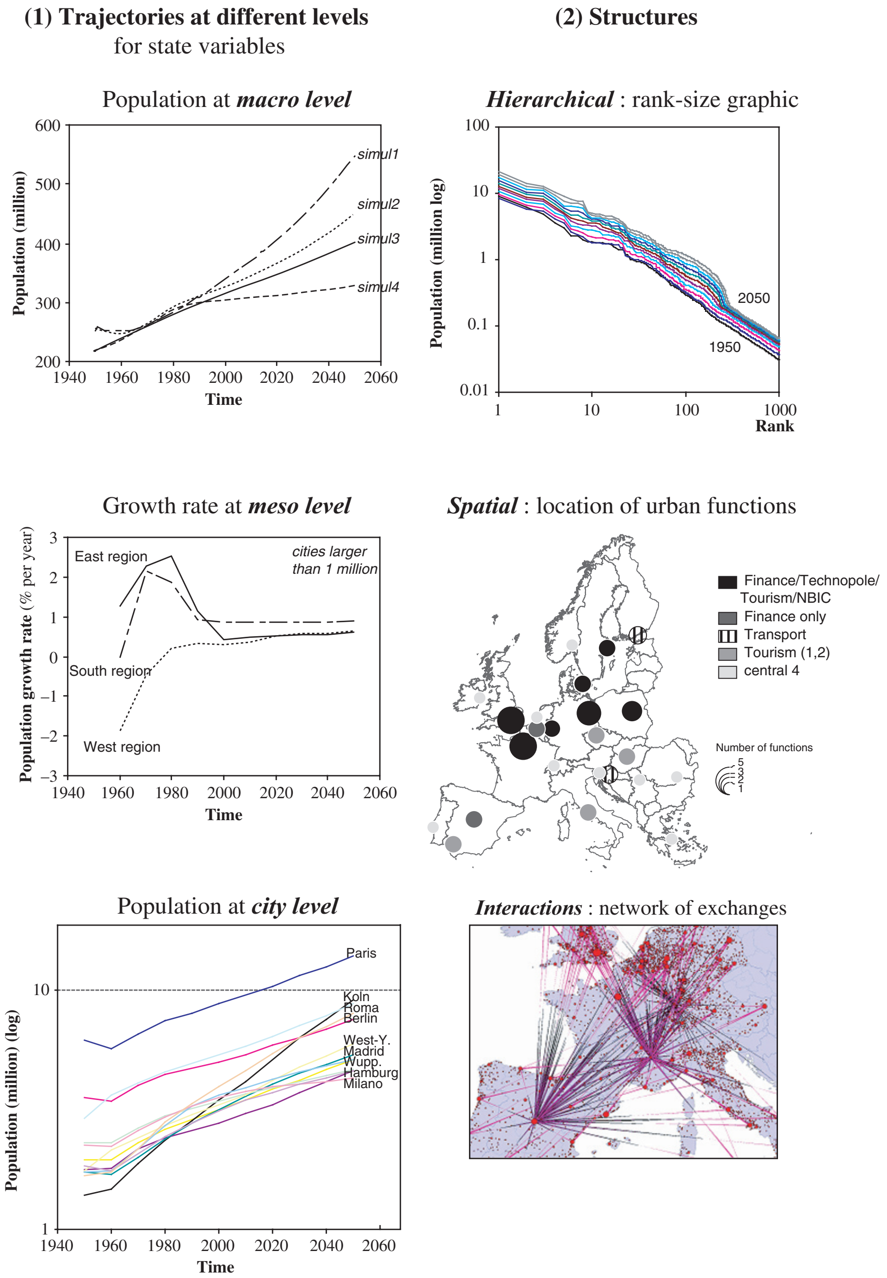

Fig. 12.8 An integrated set of outputs for validation

– local trajectories for all cities attributes: population, wealth, labor force, growth rates. . . and
– spatial structures of exchange: maps of the market networks, maps of exchanges flows, evolution of the size of the networks.

Depending on the steps of the calibration and validation phases, specialized reports may be edited for insights on specific dimensions. Multiple checks guaranty the coherence of the calibration, whatever the scale.

12.6 Results of Simulation

The assessment of SIMPOP2 abilities as an exploratory tool for the future of urban system is still in progress (Pumain et al., 2006), and further research is described on SIMPOP's website (http://www.simpop.parisgeo.cnrs.fr/). Meanwhile, we have selected a few results that seem of importance for validating our simulation approach. From the available experiments with the model, we present three examples illustrating its ability to represent urban dynamics in a consistent way and, then, discuss how it can be used in designing scenarios for the future of urban systems.

12.6.1 Simulating the Resilience of Urban Systems After External Perturbations

The model is flexible enough to reproduce huge variations in state variables at macro level as well as in many individual trajectories of cities that happened in the long history of urban systems. Some examples of such catastrophic political events that cannot be embedded in the "normal" evolutionary process of an urban system are the momentary recessions due to wars (observable during Napoleonic Wars at the beginning of 19th century, or the world wars 1914–1918 and 1939–1945). Another interesting "random" historical event is the Black Plague starting in 1348, which was followed by a period of urban population decline in huge but variable proportions from 20 to 50% according to the European regions. We tried to simulate such a catastrophic event with the model, at first by replacing the value of the demographic trend parameter that had been smoothed over the whole period by zero growth during the five last decades of the 14th century. The model reacted well, proving its sensitivity, but was not able to simulate the totality of the sharp decrease observed. It is only by also reducing the intensity of trade exchanges during that period (modifying the parameters of market return and attraction on labor force), that we were able to reproduce the observed population decrease during the 1350–1400 period and its rapid recovery during the following fifty years (Fig. 12.9). The time of reaction of the model to a change in key parameter values is not too long and the model can thus be used for analyzing the effects of societal events or changes in urban practices that occur on medium time scales (a few decades).

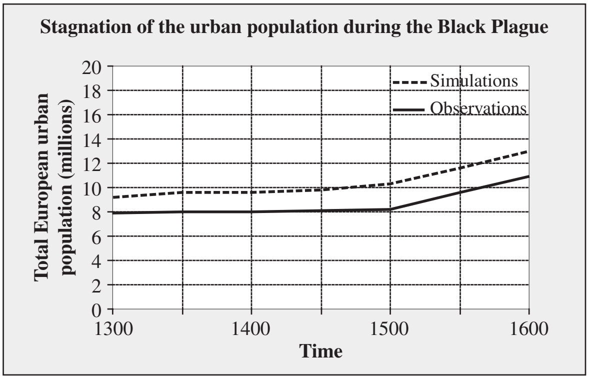

Fig. 12.9 Simulating system resilience after external choc

12.6.2 Global Cities Since the Middle Age?

While calibrating the SIMPOP2 model, we discovered that it was impossible to reproduce the size of a few cities whose observed populations were incommensurably large, compared to the results of the simulations. This happened at all periods in the evolution of the European urban system, since the Middle Age. While the population of large cities generally is simulated correctly below a given rank (for instance the second in 1500, the fifth in 1700, see Table 12.6), the population of the cities having a higher rank in the urban hierarchy is under-estimated in a systematic way. For example, in 1500, the size of the largest city (Paris) is 225,000, according to observation, whereas it is only 149,000 in the simulations, despite all our efforts to improve the fitness of the calibration by modifying all key parameters. Thus, the

Table 12.6 Observed and simulated sizes (in thousands) of the largest cities

Dates	Observations*	Simulations *	Rank of the next well fitted city
1500	Paris, 225	149	2
1700	London, 575	193	5
	Paris, 575	189	
	Naples, 500	182	
	Amsterdam, 200	162	
1800	London, 948	254	4
	Paris, 550	243	
	Naples, 430	239	
1950	London, 8900	2932	5
	Paris, 6200	2865	
	Ruhr, 4100	2733	
	Berlin, 3500	2439	
2000	Paris, 10500	6995	3
	London, 9200	6976	

Source: Bairoch et al. 1987, Geopolis 1994, Géographie-cités 2000.

functions that are present in the model are not powerful enough for generating such extra large sizes, even when they are accumulated altogether in one city. According to the period, there were between one and five such "too large" cities. A hypothesis that is suggested by other historical observations is that these cities have in common a further emerging property, stemming both from their actual combination of functions as state capital, node in maritime trade, or focus of industrial activities, and from their exceptionally central position in enlarging exchange networks progressively out passing the frame of continental Europe as well. If such exceptional urban situations were identified by Fernand Braudel as centers of "world economy," we could add another dimension by identifying centers of "world politics" (which could be a complementary explanation in the cases of Paris and Naples for instance) and summarize these two functions under the label of "world city function" (operating at a wider scale than the considered system). Its implementation within the model will help us to take into account the exceptional trajectories of cities like Paris at the head of the first large nation state since 16th century, the role of cities like London and Amsterdam in the Atlantic maritime trade in 17th century, the function of empire capitals of Paris and London during the colonialism period in 19th century and later on in industrial networks or financial activities, that are recognized today as symptomatic of "global cities". Thus, the model suggests that the function "world city" is by no means an innovation of the last decades of 20th century! Further, the European system has to be considered in co-evolution with the rest of the world, earlier than expected, through these world cities that act as inter-systems gates (which are multiplying nowadays due to globalization).

12.6.3 Reaction of the Urban Systems to an Innovation of the 20th Century

Another example of resilience and adaptation of our model of urban systems was provided while testing the sensitivity of the Eurosim model to exogenous events. As mentioned in Table 12.1, the function named "Technopole" is acquired at different dates by specialized cities: a few large ones own it since 1950, and, according to the principle of hierarchical diffusion, a few medium sized cities (seven cities of 200,000 to 1 million inhabitants) acquire it in 2000. The simultaneous acquisition of this specialization by so many cities catching this new urban function, introduced a strong perturbation in the system, as illustrated in Fig. 12.10. The curves represent the evolution of the number of employees in a completely different urban function, the financial one, for different simulations corresponding to three slightly different configurations of parameters used during the test (Sanders, Favaro, Glisse, Mathian, & Pumain, 2006). The evolutions are globally similar, including a large peak in year 2000, with only small differences in the intensity and timing of shorter fluctuations. This result illustrates the effectiveness of interactions between the different functions: due to the requirement of new capital funds for investing in the technological innovations, the cities owing the "*technopole*" function are among those that have the strongest demand for the finance sector. Seven new cities expressing a demand

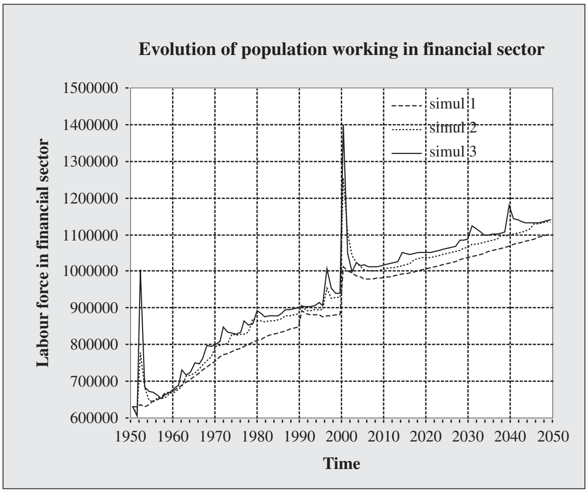

Fig. 12.10 Pertubation and adaptation after an innovation

result thus in an imbalance between supply and demand and the existence of an important potential of unsatisfied demand. The rule expressing the return from the market on the labor force quite naturally leads to an important increase in the finance sector employment for each supplying city. This increase is particularly important when the parameter measuring the speed of adjustment is high, which is the case for the two curves which register the highest peaks on Fig. 12.10. Moreover, this reaction shows the ability of the system to integrate sudden change, as the three curves representing the labor force in the finance sector recover their previous growth trend only two periods later. The shock is integrated, the effect of the newcomers is diluted, and the urban system has shown its fundamental resilience and adaptive capacity.

12.6.4 Predicting Future Trajectories for Individual Cities

The Eurosim model has also been used to test different scenarios on the evolution of the European cities during the 1950–2050 period (Sanders et al., 2007). To investigate what kind of consequences different contexts could generate in terms of urban structure as well as of individual cities' evolution, scenarios concerning possible future economic and demographic environments were imagined. Four extreme situations have been defined by combining hypotheses relative to the evolution of the demographic context on the one hand and to policies in matter of intra-European exchanges on the other hand:

– Two demographical alternatives are defined using IIASA's predictions: they correspond respectively to an hypothesis of *high demographic growth* (IIASA'S more optimistic predictions which means a very slightly positive growth rate); and of *low demographic growth* (IIASA'S more pessimistic previsions which means a clear negative trend for all Europe);

– Two political alternatives are introduced concerning the presence or absence of *barrier effects* between Eastern and Western Europe. The existence of barriers will reduce the possibilities of exchanges between cities located in the two geographical regions.

The model demonstrates that cities do not react the same way to such changes in demographic and political contexts. As an example, Fig. 12.11 represents the simulated evolutions of Barcelona's, Hamburg's, Warshaw's and Glasgow's populations according to the two extreme scenarios. These outputs also illustrate the ability of the model to produce qualitatively different city behaviors. Fig. 12.11 represents the evolutions of four cities with same specialization, "Technopole", for the period 1959–2000 according to these two extreme scenarios, no barrier and high demographical hypothesis on the one hand, barriers and low demographical hypothesis on the other. Quite naturally the trajectories corresponding to the first case predict higher growth (Fig. 12.11a) than for the second case (Fig. 12.11b). More interesting, qualitative differences appear between the two scenarios concerning the relative positions of the cities. The case of Glasgow for example is noticeable. This city suffers more than the others from the barrier effects. While the city almost rises to the level of Barcelona in the scenario without barriers, it remains far behind when barriers between blocks are introduced. In other respects, the growth of Warszawa seems to be more affected by the bad context of the second scenario than Barcelona, in the sense that the first catches up to the second more quickly in the first scenario.

There is no explicit rule in the model that would produce a more sustainable growth for economically diversified cities. The result expresses the combination of multiple interactions between couples of cities. As such, it is a consequence of self-organization processes. The model can then be used as an experimentation tool in order to explore the consequences of different constraints on interurban exchanges.

12.7 Conclusion: is the Future of Urban Systems Predictable?

Because of the many uncertainties about the future of cities, there is a need for exploratory models that could help determine the most plausible trends in their development. Of course, such models cannot be exactly predictive, since we know that predictions are often intractable for the underlying complex systems, especially in the long term. According to our method of data-driven simulation, the laws of urban dynamics presented in Chapters 6 and 8 are useful for validating an urban model, according to an acceptable representation of the past, but they have to be adapted and revised before using it as a predictive tool, as demonstrated in the Eurosim application. The SIMPOP2 model could also help in designing policies, by helping to estimate the relative cost of different choices. Is a polycentric development compatible with objectives of sustainable development? Can European cities keep their global competitiveness by sharing the investments dedicated to performing activities? Or should such investments remain concentrated in places offering the

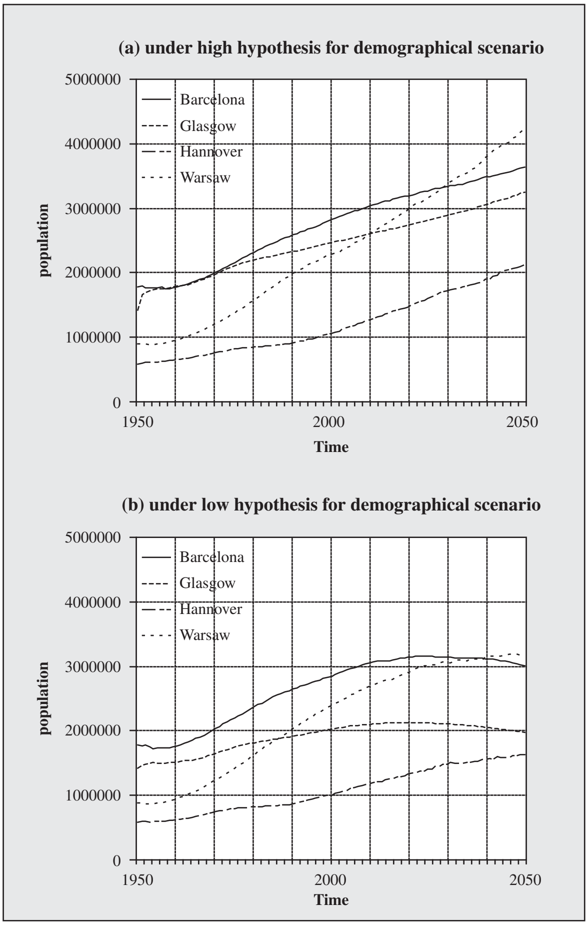

Fig. 12.11 Future trajectories of a few technopoles according to Eurosim

highest returns? How strong are the links between the objectives of social cohesion and the spatial distribution of population and income?

Despite the accumulated knowledge from comparative studies on urban systems dynamics, many uncertainties remain about their possible evolution within a near future, i.e. the next hundred years. Two different kinds of events of the period may interfere with the existing dynamics that we have reported: those that come from inside the systems and those that arise from outside, from the societal environment of the system. In both cases, the conditions of interaction between cities are affected, and some effects of major shocks are already perceptible.

The first context that will introduce major changes in urban system dynamics is linked to the variations in the urban transition in different parts of the world. In developed countries, the question is how will the systems of cities evolve once they have "won" *all* the population in a given territory? Will they keep the same dynamical features as during their period of emergence and consolidation? What future can be expected when there is no longer migration from rural areas or local demographic growth for sustaining the cities development? To what extent is a continuous population flow from outside (immigration from rural areas or foreign countries) or a minimum population growth necessary for maintaining their hierarchical organization? Some major turning points have already been observed in the evolution of urban systems. After a long period of spatial concentration, including an increase in urban population densities, the last four of five decades have been marked by local trends towards a de-concentration of resident population. Urbanized areas have expanded in surface much more rapidly than through demographic growth. This trend is sometimes interpreted as expressing the preference for rural places of residence; that would lead to a "counter-urbanization" (Berry, 1976), both at local and regional scales. On the other hand, trends toward concentration at a higher scale are observed. Will population and activities continue to concentrate in areas close to the largest metropolises? Are the small- and medium-sized isolated towns condemned to decline and disappear, as did so many villages in the past?

Both trends are suggested by our accumulated knowledge about past urban dynamics, but we should think of possible reversals that may happen because of completely different processes. Among the most frequently remarked potential changes are the demographic recession (population growth rates have been above 1% per year for two centuries, but they have recently become negative in some countries); the preoccupation for environmental quality and preservation of resources (which may hamper the further development of large cities); and new technologies for the circulation of information (which may change the relationships between the conception of cities, as places of work and residence). Thus, the "counter-urbanization" hypothesis could prevail and lead towards less inequalities in city sizes, a new population dispersal and a relative decay of large metropolises. The magnitude of the consequences of such processes can be implemented in the model by varying the values of some parameters. Meanwhile, measuring urban performance by population growth is a convenient, traditional way that facilitates comparisons in time, since there was a good parallelism between increase in the inhabitant number and the quantity of accumulated resources in systems that were not too heterogeneous. In the future and especially for comparisons at world scale, because the differences in standard of living are much higher, a more adapted measurement of the economic and social performance of cities like GDP or HDI would be needed (but is not yet provided by most statistical sources about cities all over the world, China excepted).

Reversals in dynamics also could come from "outside" the systems of cities, whatever their economic level: as the urban transition is continuing in developing countries, with unprecedented demographic growth rates, very large cities are becoming more and more the specificity of the urban systems in poor countries (Moriconi-Ebrard, 1993). In parallel, the globalization of economy and social information is developing new networks and increasing interdependencies between cities in the world (Taylor, Derruder, Saey, & Witlox, 2007). The disequilibrium between the hierarchy of city sizes according to their population and their gross product or income obviously is not sustainable over very long periods of time. Moreover, the evolution of national or continental urban systems according to their own evolutionary path cannot be prolonged independently of the overwhelming trend called "globalization." This trend may be seen as an "external shock" to many urban systems, because of its wide spatial extent and simultaneity in time, but, of course, it has been generated itself by the expansion of urban systems and the emulation of innovations that their dynamics is generating.

As it was the case for all previous innovations, the effects of that global integration on urban systems are predictable and measurable with the help of the SIMPOP2 model. At least in a first stage, the differences in accessibility to the newly created resources will be widening. As such, they may constrain the urban systems to keep a trend of concentration in the largest cities, because of the stronger competition between them. As demonstrated by Sassen (1991), very few centers in the world are concentrating the major parts of global finance, and it is not yet sure if the further developments of these activities can percolate in a larger number of "global cities" around the world. It is also uncertain if the traditional powerful urban centers have the capacity for maintaining their position in the emerging global city networks, or if they will be successfully challenged by new places of interest for investors (Hall, 1999). Meanwhile, new urban specialization may emerge in connection with the innovative economic sectors (Gaspar & Glaeser, 1996). The model can predict the general evolution of urban systems but, of course, not the exact location of these emerging new urban functions.

However, what we retain from our observations in Chapters 6 and 8 as well as from our experimentation with the model is that much regularity and universal rules can be expected in the evolution of any urban system. The major trend of historical path dependence illustrates best the capacity of resilience of such systems, their ability to absorb so many quantitative and qualitative changes in social organization without modifying their basic organization. Moreover, from that specific ability, *urban systems can be considered as "adaptors" of the spatial organization of societies subject to cultural, economic and technological changes. The SIMPOP2 model is a relevant, efficient and flexible tool for exploring their future evolution*.

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