Project no.
035086

Project acronym
EURACE

Project title
An Agent-Based software platform for European economic policy design with heterogeneous interacting agents: new insights from a bottom up approach to economic modelling and simulation

Instrument STREP

Thematic Priority IST FET PROACTIVE INITIATIVE "SIMULATING EMERGENT PROPERTIES IN COMPLEX SYSTEMS"

Deliverable reference number and title
D2.1 Agent-based computational economic modelling guidelines

Due date of deliverable:
31-01-2008

Actual submission date:
31-01-2008

Start date of project: September 1st 2006 Duration: 36 months

Organisation name of lead contractor for this deliverable
Université de la Méditerranée - GREQAM

Revision 2

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Modelling Guidelines for EURACE

Annotated Deliverable 2.1 (revised version)
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January 30, 2008

Contents

1 Introduction

Two very general guidelines are underlying the project, one concerning the modelling of agent behavior and one concerning the modelling of market mechanisms.

Bounded rationality:

> "Models of human judgement and decision-making should be build on what we actually know about the mind's capacities. Because of the mind's limitations humans must use approximate methods to handle most tasks." (Simon, 1990)

Market micro-structure:

> Models of market mechanisms should be build on what we actually know about the market's interaction protocols and institutional structure, rather than on what seems to be optimal and efficient.

As a direct consequence, we mostly focus on models in the realm of Behavioral Economics, using evidence both from empirical data and laboratory experiments. Part of this evidence is collected by scientist working outside the field of economics. This should be seen as an advantage rather than a disadvantage since such studies shed new light on aspects of economic decision making that may not have been thoroughly considered by economists themselves.

The main references for the modelling of firm behavior are: on firm organisation (Cyert and March, 1963/92), on the evolutionary theory of firms (Nelson and Winter, 1982), and on the financial policy of the firm (Myers, 1984, Pecking Order Theory).

For the modelling of households, the main references are taken from the psychological literature on decision making: Prospect Theory (Kahneman and Tversky, 1979), Psychology and consumer choice (Thaler, 1990), Saving behavior (Deaton, 1991), Buffer stock saving theory (Carroll, 1997), EWA learning (Camerer and Ho, 1999).

Combining the insights from these studies leads to a well-balanced alternative to the paradigm of rational intertemporal optimization. Furthermore, the empirical evidence is strong enough to justify our move away from the mainstream paradigm. Our modelling choices must be evidence-based since we are trying to provide a methodology to turn economics into a positive social science based on testable hypotheses about economic behavior.

2 Modelling choices and motivations

2.1 Model implementation

The different parts of the model (goods, labor, credit and financial markets) should be implemented incrementally, starting with simple versions of small parts (e.g. just the market protocol). These simple versions gradually will be made more complex as the project progresses.

The economic processes that affect a certain market will be at first modelled as exogeneous processes. Later on, when the markets are integrated, these will be replaced by the actual output from the other markets.

Once the model has been designed and implemented, it should be internally validated by running unit tests. A unit test specifies inputs and outputs for a given model element (which can be a small piece of code, a function, or a whole market mechanism).

When all model elements have been tested in this way and shown to function up to specifications they can be integrated. The integrated model should then be tested again by running a

new set of tests that are appropriate for the integrated model as a whole. The individual unit tests should also be run after the integration phase, in order to make sure that the integration does not break the functioning of the separate model elements.

Working incrementally by starting from simple isolated modules may allow to some extent to keep track of the causal chains in the integrated model. But we have to keep in mind that emergent phenomena may arise from the integration process.

2.2 Number and types of agents

The FLAME framework makes a distinction between agent types and agent roles for each type. In the model we have fundamentally two classes of agents: active agents who take decisions, and passive agents who do not.

2.2.1 Active agents

The active agents are those found in standard macroeconomic modelling: households, firms, banks, several national governments, a central bank. A list of agents and their respective roles is given in Table 1.

	Agent roles					
Market	Household	Firm (CGP)	Firm (IGP)	Bank	Government	Central bank
Labor	worker	employer	employer	-	-	-
Consumption	buyer	seller	-	-	-	-
Investment	-	buyer	seller	-	-	-
Credit	depositor	borrower	borrower	lender	-	regulator
Financial	investor	seller	seller	investor	bond issuer	regulator
Public sector	tax payer	tax payer	tax payer	tax payer	tax collector	-

Table 1: Markets, agents and roles. CGP = consumption goods producer, IGP = investment goods producer. The public sector roles include the payment/receipt of government benefits and subsidies.

One of the main goals of EURACE is to analyze whether qualitative properties of phenomena arising in economies with (locally) interacting heterogeneous agents change as the number of agents involved is increased. Certain phenomena at the macro level may require a sufficiently large population of active agents in order to be stable. The central limit theorem applies to infinitely large populations, but not to finite ones. This raises an important normative research question: Does the large-type limit hold? That is: *As we increase the number of active agents in the model, do we reach the results predicted by the central limit theorem?* A related question is how the results of large-scale agent-based models scale as we increase the number of active agents. Do small- and medium-size populations produce the same aggregate phenomena as large-size populations? These questions have still been largely ignored in agent-based computational economics up till now.

Thus motivated, EURACE should be designed to be able to handle a large number of active agents (up to millions). This number will possibly remain much smaller than the actual population size of the EU. However, in order to ensure robustness of the results, the number of agents will be chosen such that the qualitative results of the policy evaluation exercises can be expected to remain invariant with respect to an increase in the population size.

2.2.2 Passive agents

The passive agents embody market institutions in a stylized way. They typically collect micro data, produce macro variables and forecasts and then redistribute this data down to the micro level. This allows the active agents to realistically base their decisions on both local and global information. The passive agents are:

- Local outlet malls: agent that performs the selling role of the firms in the region. It receives inventory stock from each firm, then sells the goods and collects sales revenues that are reported back to the firms.
- Eurostat: collects aggregate statistics at the macro level and publishes it to the public.
- Market research entity: collects data on regional markets (anticipated local demand and market share for several outlet malls) and reports this data to the firms.
- Clearinghouse: collects stock orders, computes clearing prices and transactions. It replaces the market clearing equation on the financial market.
- Financial Advisor: an agent who collects information about the past performance of a set of portfolio allocation rules (investment strategies), and then distributes this information to the individual investors (this is used in the learning algorithm).

For further details, see deliverables D5.1, D6.1 and D7.1.

In addition, the financial market model contains Asset Management Companies that are agents that manage asset portfolios for individual investors. They use relatively sophisticated investment strategies (using longer time horizons for example, or more sophisticated risk measurements).

2.3 Entry and exit of agents

All agents are infinitely lived, with the exception of banks and firms. These can go bankrupt and newly created as a function of local and/or global profit opportunities. Concerning the outlet malls we make the assumption that every cell in the geographical space is a potential mall and can be selected by a firm to sell its output. That is, the geographical distribution and number of malls can change over time, as a function of the decisions of the firms. This will allow us to study phenomena of firm concentration and desertification.

2.4 ROW and energy sector

The energy sector will be modelled as exogenous and the energy price will be used as a parameter in policy scenarios. In the first stage of development the ROW will be modelled as simple exogenous processes. This will be sufficient to analyse the impact of exogenous shocks on the EURACE economy.

2.5 Choice of markets and sectors

EURACE includes all the main markets and sectors that are found in general purpose macroeconometric models. The finer level of details to which these will be modelled should be driven by the set of policy questions we want to address within EURACE and its medium-term follow-up.

There exists a clear description of policy questions that we are going to address (see the Vision document).

For example, WP 7 foresees an analysis of the relationship between higher levels of general skills, the speed of adaptation of specific skills to the technologies used within firms, and long run growth. To conduct this task we need to have heterogeneous labor with respect to skill levels, a sector producing capital goods that are used in the final good sector and labor to produce a consumption good. These considerations led us to make the modelling decisions documented in D7.1.

On the other hand, one should make sure that given the policy questions of interest, the model should be kept as parsimonious as possible and that the data requirements to calibrate the model parameters can be satisfied. Thus for example, in WP 7 it was decided not to incorporate a differentiation of production sectors that goes beyond the standard distinction between investment and consumption goods. Indeed, an additional differentiation would not generate additional qualitative policy insights, but would substantially increase the complexity of the model and the data requirements.

2.6 Decision processes

In the model, the government and central bank will follow simple rules that can be found in the literature (e.g. a Taylor rule for the central bank), or they are chosen for policy analysis purposes.

In modelling the other active agents' decision making processes, we follow the usual assumptions of agent-based economics regarding bounded rationality, limited information gathering and storage capacities, and limited computational capabilities of the agents. These assumptions lead us to use simple heuristics to model the agents' behavior, derived from the management literature for firms, and from experimental and behavioural economics for consumers/investors.

We shall use simple but not necessarily fixed rules, in the sense that their parameters can be subject to learning, making them adaptive to a changing economic environment. The modelling of learning algorithms should be done at different levels of sophistication depending on the kind of decisions that are taken. The choice of learning mechanism should be based mainly on the following empirical criteria:

- the information available to the agent, including the possibility to imitate or communicate;
- the frequency of decision making and the number of observations available;
- the stakes of the decision.

To give an example illustrating different choices for the same market, consider the consumption goods market. The learning mechanism of the firm differs from that of the consumer.

Firms decide where to sell (that is, choose local outlet malls) based on the information they obtain from the market research entity. This information consists of anticipated local demand and market share. The decision to service a particular outlet mall is infrequent (yearly) but the stakes are high. The learning mechanism used here should be fairly sophisticated because the firms' decision is important.

For the consumers, where to go shopping has low stakes. The potential advantages to switch between outlet malls are small compared to the costs of making the switch. The information about prices and quality of goods at the other malls is poor. This suggests a relatively high

frequency but a low level of sophistication in the decision-making process. The learning mechanism should therefore be simple and based on some form of reinforcement. Word-of-mouth effects may play an important role and could be modelled as group learning or social learning.

As previously stated, we shall model a Eurostat agent that collects data at the macroeconomic level and produces key economic indicators such as the employment level, inflation rate and the GDP growth rate, as well as forecasts using standard econometric tools. These are then redistributed and fed back into the decision making process of the individual agents at the micro level. This reflects an important empirical feedback mechanism in the economy. Moreover, doing so provides a partial answer to the Lucas critique which states that policy analysis should take into account the feedback effect of changes in individual behavior due to changes in policy. By introducing the Eurostat agent we incorporate this downward causality effect. It also allows us to study the effect of forecasts on the economic activity.

2.7 Spatial structure

The decision to give the model an explicit spatial structure and to let the agents interact locally within this structure was motivated by theoretical, empirical, and policy-related considerations.

- At the theoretical level, an explicit local interaction structure in space and time is arguably the most salient feature of an agent-based model. Such an interaction is sufficient, even with extremely simple homogenous agents, to generate phenomena that typically would not arise in a "standard" framework (think of the Schelling segregation model e.g.)
- At the empirical level, we want at least to take into account the main elements of heterogeneity between the different regions in the EU - the distribution of economic activity and of wealth. In order to do so, we want a model that captures various geographical scales.
- At the policy level, many issues of major concern for the EU are of a spatial nature: how to distribute funds to poor areas, in which regions to invest, what regional labor market policies to set, what land use policy to promote, what is the impact of fiscal competition, what is the impact of investments in transportation and infrastructure.

We consider the EU-27 as our target system. We intend to use the NUTS-2 regions of Eurostat as the statistical units to collect aggregate statistics in order to compare the synthetic data to the empirical data from Eurostat. This will ensure a good compromise between geographical detail and modelling practicability. Three distinct geographical levels will be implemented: regional, national and supranational. Consequently, the markets and agent roles are assigned to be active at certain geographical scales:

- Supranational level: Central bank and possibly the financial market, highly skilled R&D labor, investment goods output, consumption goods output;
- National level: the governments;
- Regional level: credit market, low skilled labor market, outlet malls.

The properties of different regions will be captured by the values of model parameters within a canonical description of the economy. Thus we will not need to build separate models for each geographical region in the EU.

2.8 Local interaction

In FLAME the agents have a position given by (x, y)-coordinates. Their local neighborhood can be given either as a Euclidean distance to other agents or as an interaction radius, that is, as a local sphere of influence. Every message has a range, which specifies how far away it can be read. These features allow to model both local and long-range interactions between agents. In addition, message filters allow to exclude certain agents from reading certain messages.

The above features can vary over time. Agents can migrate. The interaction radius can change. The filters can be modified. All this gives an enormous flexibility to model the interaction among agents. This flexibility can be exploited e.g. to model the following:

1. Geographical migration of agents
2. Evolving social, transaction and communication networks
3. Word-of-mouth effects
4. Contagion effects
5. Global and local feedback effects

2.9 Timing of decisions

The choice of time scales for the agents' decisions shall reflect the empirical time scales of economic activities. Events can be calender- or event-driven, e.g., wage payments are clearly calendar-driven, while pricing decisions are event-driven. Financial decisions are made on a shorter time scale than for example consumption and production decisions. An overview of the timing of events and the frequency of decisions is given in Appendix B of deliverable D7.1, p. 42-43.

2.10 Time budgets

All processes in the model take time: decision-making, searching, information gathering, information dissemination, production and trading. This implies that agents have a limited amount of time to take decisions and perform tasks. In other words, the agents have a time budget and are time constrained.

Taking into account explicit time-budgets and the duration of activities may have and important impact on the simulation outcome and allow us at a later stage of the project to investigate questions such as the possible impact of the shortening of the work week, of faster transportation, or the effects of longer opening hours for shops.

2.11 Sequencing of interaction

In reality, most human decision-making and interaction are asynchronous, due to the autonomous decisions of the agents. We model this asynchronous decision making by letting agents have different activation days. On the same market different agents are active on different days. Thus, who interacts with whom changes from day to day.

Some activities, however, are synchronized. This is in particular the case when they are institutionally initiated. Think, for example, of yearly tax payments, or monthly wage payments. We use synchronous decision-making/interactions whenever it reflects reality.

2.12 Market taxonomy

Salient features of markets are whether they use local or global interaction (referring to the range of interaction between agents) and whether the interaction is centralized or decentralized (referring to the number of intermediators on the market, zero for a decentralized market and one for a centralized market). The following empirically inspired choices were made:

1. Labor Market: local, decentralized. Workers only search locally for jobs and there is bilateral interaction between the job searchers and firms.

2. Investment Goods Market: global, decentralized. We assume there are only few investment good producers. Consumption good producers can go to any investment good producer to purchase capital goods, so the market consists of global interaction. There is bilateral interaction between the buyers and sellers.

3. Consumption Goods Market: local, decentralized. Consumers can go to any local outlet mall to buy consumption goods, and there is bilateral interaction between the buyers and sellers.

4. Credit Market: global, decentralized. Firms can get loans from any bank, and they can go to any bank they wish depending on the credit conditions (e.g. the interest rate) that is offered.

5. Financial Market: global, centralized. There is only a single global financial market on which all stocks and bonds can be traded, and the market mechanism is either a clearing-house or a limit-order book.

An important research question will be to investigate how these different market types can be integrated into a single macroeconomic model and how they interact. This requires the definition of appropriate market interfaces with inputs and outputs between the markets. This is the topic of WP 8 that has already started at Month 12.

2.13 Type of market protocols

The modelling of the market protocols is inspired by real-world markets.

In the case of the consumption goods market all consumer-firm interactions go through the local outlet malls. The firm sends its output to the malls where it is added to the local inventory stocks. The malls sell the goods at prices fixed by the firm and report back the sales revenues, the costs of the selling activity, and the stock levels.

The consumers can decide which mall to visit on a monthly basis. They rank the firms that are present at the chosen mall according to price and quality. When they arrive at the mall the consumer has a predetermined consumption budget coming from a previous savings/consumption decision. Further details are given in the appendix of the Vision Document.

The labor market functions by way of a local search-and-matching protocol that resembles a real job search. The job seeker looks for vacancies that match its own skill level, applies to multiple job offers, waits for the responses, selects among the positive responses a job with the best conditions (highest wage), and finally sends a job acceptance message. All of these job market iterations are occurring in parallel and asynchronously with the other candidates. The firm starts with determining the number of open vacancies to post or the number of workers to fire. If the firm wants to reduce its workforce it first fires workers with the lowest specific

skill level. If it opens vacancies it sends out a job offer message containing the wage offer. For further details, see the appendix of the Vision Document.

In Europe, stock markets use either floor trading or a limit-order book for stock transactions. However, the illiquid stocks of small firms are sold by the clearinghouse mechanism. In the EURACE artificial financial market we model two of these market protocols: the clearinghouse and the limit-order book. We do not model floor trading because of lack of empirical evidence on the way it functions.

In the case of the credit market we use a firm-bank network interaction mechanism. Firms can apply for loans with at most n banks, where n is a parameter that can be set by the modeller. This reflects the empirical data concerning firm-bank network interactions available to the Consortium.

2.14 Modelling of institutional details

Within the 3-years time span of the project it will not be possible to collect data pertaining to the institutional details at the national or regional level. However, EURACE should be developed in such a way as to allow exercises analyzing the impact of regionally heterogeneous institutions. These regional institutional differences will be captured by regionally varying the model parameters, and by having heterogeneous national governments. Issues that could be addressed in such a way include:

- Regional variation in taxation and fiscal competition;
- Local reduction of transaction costs (reflecting the improvement of infrastructure or of administrative institutions);
- Local labor market regulations (wage rigidities, working hours);
- Regional variation in public expenditure on education;
- Regional variation in public expenditure on research and development.

2.15 Future extensions

We should take care that the following extensions could be realized with small overhead at a later project stage:

- **Aging and demographics**: Having a constant population of infinitely lived agents relieves us of the need to model pension savings, and thus pension funds, education expenditures, etc. In the future, it will be interesting to include aging in order to investigate the employment rate of older workers, the funding of pensions, and related policy issues.
- **Gender**: Even though many EU policies are aimed towards gender issues (e.g., female employment rate, the gender wage gap), distinguishing between male and female agents in a world without aging and reproduction would require many additional assumptions and did not seem crucial within the initial EURACE project. However, it does not seem too difficult to model gender as just another heterogeneous attribute of the agents that affects their behavior.
- **Housing sector**: The housing sector is most important for overall economic activity (approximately 50% of household debt consists of mortgages).

- **Education and health sector**: Both sectors are extremely important for economic activity within the European Union and are related to policy issues such as the local provision of health and education services, the impact on competitiveness and economic growth.
- **Explicit geographical features**: Issues such as local climate, mountains, rivers, and infrastructures (in particular, transport infrastructure) are all important for economic activity and individual decision making of firms and households. Incorporating them will lead to a richer catalogue of policy related questions and to more differentiated results. It will give a more distinctly European character to EURACE.
- **Epidemiology**: Using aggregate data to assess the impact of epidemics on economic activity is likely to be highly misleading. Our model can capture network contagion effects and may therefore provide new insights into the transmission and impact of such phenomena.
- **Endogenizing central bank and governments**: In the original description of EURACE the policies are exogenous control parameters. It may be interesting to experiment with policy makers that are modelled as adaptive purposive agents inside the model.

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