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
D7.1: Agent based models of skill dynamics and innovation
Due date of deliverable: 31.8.2007

Actual submission date: 9.10.2007

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

Organisation name of lead contractor for this deliverable
Universitaet Bielefeld - UNIBI

Revision 1

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	
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)	

Agent-based Models of Skill Dynamics and Innovation*

EURACE Deliverable D7.1
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Abstract

This document describes the parts of the agent-based model employed in the EURACE project that are the basis of the analysis of questions concerning skill dynamics and innovation. In particular the working and interplay of capital-, consumption goods and the labor market are described. The document aims at giving the reader a motivation for the modelling choices and a detailed description of the actors and their decisions which will eventually be implemented in FLAME – the simulation platform choice for the EURACE model.

1 Introduction

The EURACE project aims at developing an agent-based platform for European economic policy design. It distinguishes itself from existing models that ex-ante evaluate economic policies by rigourously applying a bottom-up approach starting from the individual level in order to study macroeconomic phenomena. Thus, from a scientific point of view one aim is to improve on the micro-foundation of macroeconomic theory. Eventually, macroeconomic policy design will be studied in a framework with a large number of interacting heterogenous agents that will be confronted with various policy measures.

*This research was funded by the European Commission as part of the FP6-STREP project EURACE ('An agent-based software platform for European economic policy design with heterogeneous interacting agents: new insights from a bottom up approach to economic modeling and simulation').

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The EURACE model is a closed model in the sense of interlinked factor and product markets. In particular, the model consists of a credit market, a financial market, a capital- and consumption goods market, and a labor market. Closed macroeconomic models using an ACE approach have been provided for example by Chiaromonte and Dosi (1993), Silverberg and Verspagen (1993), Dosi et al. (2006) and in particular by the research group in Ancona that is a partner in the EURACE project (see e.g. Delli Gatti et al. (2005)). In this paper we will describe in detail the models for the capital- and consumption goods and the labor market – specifically the actors involved and the decisions they make. While we do not spell out the details for the credit- and financial market (see EURACE Deliverable D5.1) we do point to the interfaces where the capital-, consumption goods and the labor market will be connected to the credit and the financial market.

The structure of the model described here is driven by our aim to address the research questions raised in WPs7 and 8 of EURACE. In particular, we are interested in potential interaction effects between innovative activity in firms and the supply characteristics of the labor force. We want to take account of feedback processes between innovative activities and the skill distribution in the labor force. Secondly, doing so we will distinguish between product and process innovation, and with respect to the workers, between general and specific skills. This will allow us to address different policy questions, as for example whether investments in general skills spur innovation via a faster adaptation of specific skills. Thirdly, we want to study regional questions such as whether regional variation in skills leads to variation in innovative activities across space and how regional variation in (general) skills influences the speed of technological change and income distribution and growth. Issues which policymakers are concerned about when it comes to the decision whether to allocate subsidies along clusters or spreading it more evenly across constituencies. In order to address these issues a regional dimension in our set-up is needed. Finally, the model should allow us to compare the effects of public policy measures aiming at the change of skill distributions to the effects of direct R & D subsidies or labor market policies. Since the existing macroeconomic ACE models focus on issues quite different from the ones sketched above, we develop a model that is similar in spirit to existing models but does not directly build on these approaches.

We chose to construct a model as simple as possible but still apt to address these questions. The model consists of a consumption goods and an investment (or capital) goods sector. Production of capital goods requires energy (energy markets are not part of our model, and energy is supplied at an exogenously given price) and labor. The inputs for consumption good production are investment goods and labor. Process innovation improves the quality of investment goods leading to higher productivity of capital in the consumption good production. Consumption good producers carry out product innovation to improve the quality of the product they offer. This leads to vertical differentiation of the consumption goods. The labor market hosts workers of different types. They are differentiated along their general as well as their specific skill level. A crucial assumption is that sufficient specific skills of workers are needed to exploit the full potential of the advanced technological level of investment goods like production machines. Put formally, there is complementarity between the average quality of the investment goods of a firm and the average level of specific skills of its employees with respect to the productivity in consumption good production. Empirical evidence for such complementarity can for example be found in Griffith et al. (2004). Workers of higher general skills adapt faster in terms of their specific skills needed to produce consumption goods by the use of investment goods of a particular technology and quality. General skills affecting the adaptation of specific skills will allow us to study the effects of government policies improving the general skill level of the workforce on the firm's innovation decisions. Through the firms' innovative activities and faster learning curve effects, such policies should eventually also affect the distribution of specific skills in the economy and thereby the speed of technological change and economic growth.

A general problem of agent-based models, that attempt to avoid the overly strong assumptions about information and rationality of individuals that underly equilibrium analyses, is the appropriate design of decisions rules that govern the behavior of individual agents. Deviation from the intertemporal (constrained) maximization paradigm opens many degrees of freedom with respect to the type of behavioral rules used and the way behavior is adapted over time. However, as far as firm behavior is concerned for many operational decisions like pricing, production and inventory choice, market selection decisions standard decision rules and heuristics have been developed that are well documented in the relevant business and operations management literature. Our 'philosophy' in terms of modelling firm behavior is to implement relatively simple decision rules that match standard procedures of real world firms as described in the corresponding management literature. In a similar spirit the decisions of consumers, like the allocation of the available budget between consumption and savings is modelled according to simple empirically founded rules from the literature.

In addition to making sure that behavioral rules of individual agents in the model are in accordance with stylized representations of standard decision rules employed by their real-world representatives, it is also important to critically examine the plausibility of the qualitative patterns of simulation results. A widely used approach for this kind of model evaluation in recent work in agent-based economics is to compare simulation outcomes with 'stylized facts' that have been established using real world data. This kind of comparison is supposed to restrict the region of model parameters to be considered and to improve the confidence that the model captures crucial aspects of interactions in the sectors considered in the model (Windrum et al. (2007)) for a discussion of approaches to validate agent-based simulation models). Carrying out validation exercises of this kind will be an important task in the second year of the EURACE project. While designing the model described in this document we have also collected main stylized facts in the areas of labor markets, industrial and technological change. A collection of such stylized facts, that might be used for validation of the proposed model, is given the Appendix of this document.

The model described in this paper should be seen as the structure we aim to develop till the end of workpackage WP7. In order to build up such a rather complex simulation model we follow a gradual approach where we first implement a much simpler model and then, once the behavior of the simpler model is well understood, extend that model step by step in order to incorporate the different effects that seem to be most crucial for addressing our research questions. The full model described here should be seen as a guideline for such extensions to make sure that they are embedded in a unified framework. As a first step we have implemented a simplified version of the model, where several aspects have been neutralized. The simplified model is described in Appendix A. This on the one hand allows us to check the plausibility of outcomes generated by the central parts of the model (consumer-producer interactions in the local malls, worker-firm interaction through the labor market) before we extend the model and, on the other hand, help us to disentangle the qualitative effects responsible for the phenomena we will observe in the full model. The implementation of the simplified model in the FLAME framework has been finished which constitutes the first milestone (M7.1) of workpackage 7 as described in our original workplan. Results of initial simulations of the implemented model are very encouraging in a sense that several observable patterns of aggregate variables seem to be in good sync with real world observations. More systematic testing and analysis is under way. Extensions of the simplified model will be guided by this document, but based on insights from the initial simulations and intense discussions with the parnter units. Therefore deviations between the model described here and the full model that will be implemented are possible and maybe even have to be expected.

We proceed in this paper as follows. In the next section we give an overview of the general features of our model. After this bird's eye view we go into more detail describing our modelling assumptions for the capital goods market, the consumption goods market, and the labor market. The last section concludes. In Appendix A we provide a short description of the simplified model, an overview over the timing of different events is given in Appendix B and a list of variables for the full model is given in Appendix C. Finally, Appendix D provides a collection and short discussion of stylized facts in the areas of labor markets, industrial dynamics and technological change.

2 General features

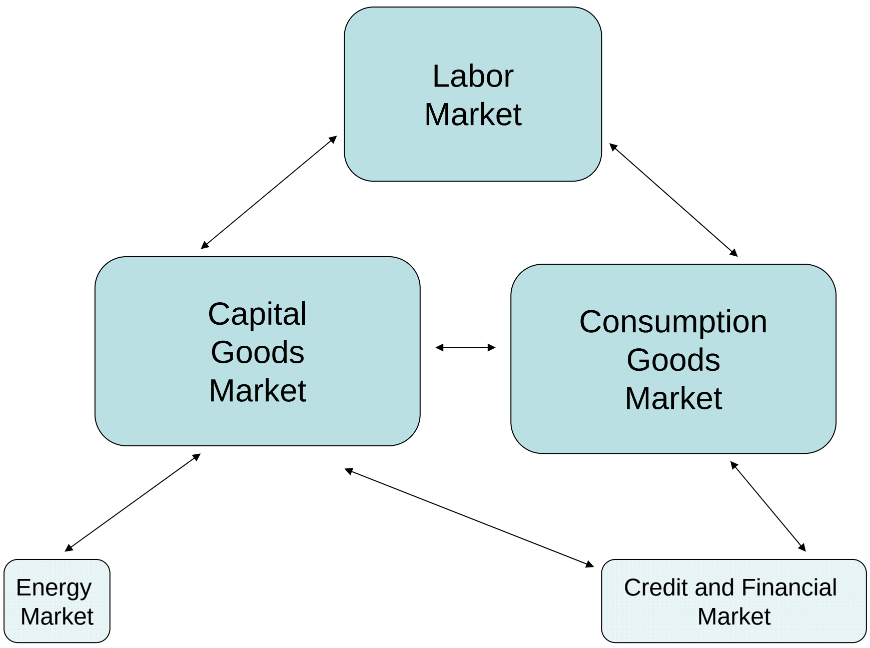

Figure 1: Market interaction

The EURACE model consists of a capital good, a consumption good, a credit, a financial, a labor and an energy market (see van der Hoog and Deissenberg (2007b)). The energy market is exogenous to the whole set-up. It constitutes a proxy for the link to the 'rest-of-the-world' via exogenous energy prices affecting the production costs in the capital goods market. Here, in the description of the capital good, consumption good and the labor market we treat the credit and the financial market as exogenous. In the full EURACE model these markets are present as agent-based models and interact with the markets described here through interfaces.

We consider two real sectors in which consumption goods and capital goods are produced, respectively. The labor market is populated with workers that have a finite number of general skill levels and acquire specific skills on-the-job.

In the capital goods market we have a small number of investment goods producers. Each of them produces an investment good that is based on a particular technology. As inputs any investment good producer uses workers that have low general skills and energy. The quality of a particular technology of an investment good can be improved by investments in R&D. Downstream we have many firms in the consumption goods sector. They produce a vertically differentiated consumption good. Product innovation by a firm in the consumption goods sector improves the quality of its consumption good. Consumption goods are produced with investment goods that can be bought from firms in the capital goods sector and specifically skilled labor. Consumption goods are sold at malls which are spread out across regions. Malls are not treated as profit-oriented enterprises but simply as local market platforms where firms store and offer their products and consumers come to buy goods at posted prices.

The following three types of active agents and two types of passive agents (in the sense that this type of agent does not take any decisions) are present in the model. Each type of active agent has several 'roles' corresponding to its activities in the different markets. Each activity of an agent is connected to one of its roles. Regardless of its current role each agent can always access all its internal memory variables (like savings, available budget, stock of employees, skill level). Therefore, these internal memory variables represent the connection between the different roles of an agent.

Active Agents:

- Households
  - Consumption Goods Market: Role of Buyer
  - Labor Market: Role of Worker
- Investment Good Producers
  - Investment Goods Market: Role of Seller

- Labor Market: Role of Employer

- Consumption Goods Producer
  - Investment Goods Market: Role of Buyer
  - Consumption Goods Market: Role of Seller
  - Labor Market: Role of Employer

Passive Agents:

- Malls
  - Consumption Goods Market: Information Transfer between Consumption Goods Producers and Households

- Market Research Entity
  - Consumption Goods Market: Collects Information about Consumer Behavior and Transmits Demand Estimation to Firms

The considered economy consists of R regions and each agent is located in one of these regions. Regions are arranged in a rectangular grid thereby determining the neighborhood structure of the economy. As will become clear several transactions, like most labor market interactions, occur locally, i.e. only agents that are located in the same region interact, whereas markets like the investment goods market work globally.

Generally, the minimal unit of time in the EURACE project is a day, however almost all the interactions and decisions dealt with in this document are repeated on a monthly basis[1]. Therefore, whenever we refer to one time-period in this document by default we mean one month. Some decisions in the consumption goods market are taken on a weekly basis and we will explicitly point out this fact in the text. In accordance with the general approach in EURACE the implementation of the described model will feature deterministic but asynchronous timing of the decisions of different agents. To give an example, each firm determines its production quantity once every month and each month at the same day (e.g. day 5 of each month). Different firms however do so on different days of the month such that decisions are taken asynchronous and undesirable artificial overshooting effects are avoided. The activation day for each such decision of an agent is randomly set in the beginning of the simulation. In addition to these calendar time driven events

[1]In EURACE each week consists of 5 days and each month of 4 weeks. Accordingly, each year has 240 days.

there are some event-driven actions – those actions which depend on the occurrence of another event. The timing of all events is summarized in the Appendix B.

3 Capital goods market

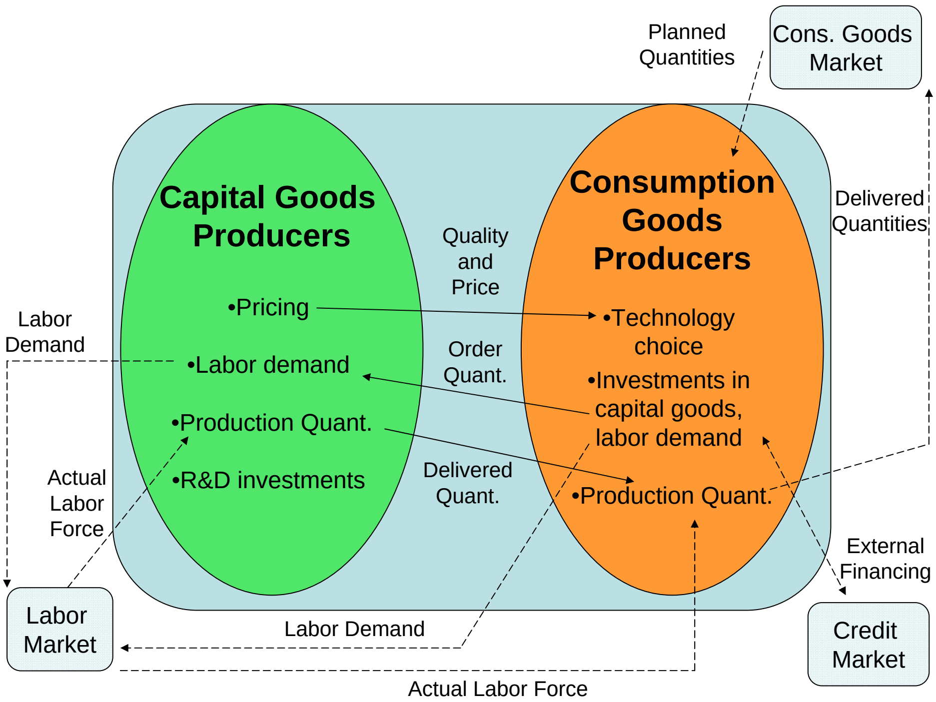

Figure 2: Capital goods market

The capital goods market is assumed to be a global market with a small number of investment goods suppliers. Consumption good producers derive their demand for investment goods (and labor) from their output decisions on the consumption goods market. Based on information about product price and quality posted by investment goods producers they then place orders with a certain investment good producer where we assume that geographic proximity does not play a role in that decision. Investment good producers are assumed to produce on demand after an order has been placed. Figure 2 gives a schematic overview of the decisions taken by the two types of agents in the capital goods market and the relevant information flows. Solid arrows represent information flows through messages sent between different agents, whereas dashed arrows indicate virtual information flows within an agent that link decisions taken by the same agent in different roles on different markets.

3.1 Capital good producers

An investment good producer j produces investment goods based on technology j. We denote with $INV(t)$ the set of existing investment good technologies which is equal to the set of investment good producers at time t. The assumption that there is a one-to-one correspondence between investment good producers and investment good technologies is of course somehow restrictive but reduces significantly the complexity of the interaction on the investment goods market. We assume heterogeneity of technologies embodied in the investment goods in order to address in a sensible way issues of 'specific skills' of workers and the value of general skills in a sense that workers with higher general skills adapt faster to specific skills which are necessary for the production process of the consumption good (see section 3.2.1).

3.1.1 Production

Investment good producers have a constant coefficient, constant returns to scale production function, which depends solely on labor and energy. Since energy markets are currently not part of the model the use of that input is considered only as a cost factor and we can write

$$Q_{j,t}^{inv} = \gamma L_{j,t}^{inv}. \tag{1}$$

For a given wage level w_t and energy price e_t production costs for a firm in the investment good sector read $c^{inv}(Q_{j,t}^{inv}) = (w_t + e_t)Q_{j,t}^{inv}/\gamma$. The assumption that no physical capital is used for the production of investment goods is simplifying but in line with assumptions made in the new growth theory literature (Aghion and Howitt (1992)) and in existing agent-based models with separate investment good sectors (e. g. Dosi et al. (2005)). Specific skill levels of workers are irrelevant for the production of capital goods and matter only for the production of consumption goods. Since our main focus is on the effect of the complementarity between the level of specific skills and the level of technology of capital goods in the consumption good production, we disregard for reasons of simplicity the effect of general and specific skill levels in the production of investment goods.

3.1.2 R&D investments

Moreover the investment good producers undertake research and development to increase the productivity $q_{j,t}^{inv}$ of the capital good they offer. Denote by $L_{j,t}^{RD,inv}$ the number of R&D workers employed by firm j at time t, then the probability that the innovation project is successfully completed in a given month is $\min[1, \gamma^{inv} L_{j,t}^{RD,inv}]$, where $\gamma^{inv} > 0$ is a parameter expressing the efficiency of R&D activities in the investment goods sector. If a project is successfully completed this leads to a change of the quality of the offered good by $\Delta q_{j,t}^{inv}$ by $q_{j,t}^{inv} \max[0, \bar{q}_{innov}^{inv} + \iota]$, where $\bar{q}_{innov}^{inv}$ is the average percentage-increase in product quality induced by an innovation and ι is stochastic with mean zero. In the following period the firm starts a new innovation project. It should be noted that this specification induces a memory-less and approximate exponential distribution of the completion times of innovation projects.

The number of R&D employees is reviewed and updated by the firm once a year. In order to determine the target number of R&D employees the firm estimates the wage per high-skill employee as $w_t^{RD,e}$ and estimates $\Delta\hat{R}_{j,t}$ which is the expected discounted additional revenues generated over a time horizon T by a quality improving innovation. The estimated additional revenue $\Delta\hat{R}_{j,t}$ is calculated based on data from the revenue effect over T periods of the last successful innovation, where these numbers are multiplied by the ratio of the expected quality increase to the actual quality increase of the last innovation (see Colombo et al. (2006) for a similar procedure).

Under our assumption that the distribution of development time is memoryless and approximately exponential, the problem of the producer to choose R & D effort at time t is independent from the time the current innovation project was started. The expected net profit from increasing R & D effort by one worker is given by the difference between the expected increase in future revenues due to successful innovations and the labor costs associated with an R & D worker. Firms use a simple rule where the target level of R&D employees is proportional to this difference:

$$\tilde{L}_{j,t}^{RD,inv} = \kappa_j^{inv}(\gamma^{inv}\Delta\hat{R}_{j,t} - w_t^{RD,e}). \qquad (2)$$

The parameter $\kappa_j^{inv} \geq 0$ is a strategy parameter of the firm expressing its propensity to invest in innovative efforts.

Since R&D decisions are strategic decisions which are taken with lower frequency than production decisions we assume that firing costs are not taken into account and the firm intends to adapt its R&D labor force according to this optimal value. Actual R & D effort might deviate from this level if the firm is unable to hire the demanded number of high-skill workers, hence we have $L_{j,t}^{RD,inv} \leq \tilde{L}_{j,t}^{RD,inv}$.

3.1.3 Pricing

Investment good producers update their prices whenever their innovation efforts have resulted in an increase of the quality of the good they are offering. The pricing of the investment goods by the investment good producer will be based on standard economic value considerations as described in Nagle (1987). There, the economic value to a customer is seen as the sum of the product's reference value and its differentiation value. The reference value is the cost of whatever competing product the customer sees as the best substitute for the product being evaluated. It equals the price of the competing product adjusted for differences in the used quantity. The differentiation value is the value of a product's attributes that are different from those of the best substitute. The differentiation value can be positive or negative.

The economic value to a customer of an investment good with a higher productivity than the machine of a competitor would be the price of the competing machine plus the value of the labor respectively material savings induced by the better technology. Thus, the analysis of the economic value provides the investment good firm with a ceiling for the new machine's price which is the highest price a fully informed customer would pay. Applying the economic value analysis the price for one unit of capital will be composed of a base price $p^0_{j,t}(w^e_t, e_t)$ which is requested for a unit of capital of the initial productivity level and a component depending on the productivity advantage the investment producer is able to generate $p^{add}_{j,t}$:

$$p^{inv}_{j,t} = p^0_{j,t}(w^e_t, e_t) + p^{add}_{j,t}.$$

Let us explain the base price component $p^0_{j,t}(w^e_t, e_t)$ first. The anchor for the calculation of the economic value is a unit of capital of base productivity. The base productivity, denoted by q^{inv}_0, is the initial productivity which is assumed to be the same for all investment good producers. Given naively expected future wages w^e_t and an exogenously given price of energy e_t the investment good producer is able to calculate a minimum price which guarantees a requested operating margin – a return on investment for a unit of capital with base productivity.

The second price component $p^{add}_{j,t}$ depends on the technology advantage of the respective firm. As a better technology leads to cost savings in form of current and future labor and capital savings for the customer, these cost advantages should be incorporated in the requested price (positive differentiation value). Keeping it simple we assume that the investment good producer passes a fixed share η_j of the cost savings down to the consumption good producers. The parameter η_j can be interpreted as a strategy parameter of the firm determining how aggressive it prices its product. Overall we get the following equation, with $\tilde{c}(Q_{i,t}, q_{j,t}^{inv}, p_{j,t}^0, w_t^e)$ as total production costs using the technology j, where specific skills of the employed labor force are assumed to be sufficiently high to fully exploit the new technology:

$$p_{j,t}^{add} = (1-\eta_j)\frac{(\tilde{c}(Q_{i,t}, q_0^{inv}, p_{j,t}^0, w_t^e) - \tilde{c}(Q_{i,t}, q_{j,t}^{inv}, p_{j,t}^0, w_t^e))}{\tilde{K}_{i,j,t}(Q_{i,t}, q_{j,t}^{inv}, p_{j,t}^0, w_t^e)}.$$

The term $\tilde{K}_{i,j,t}(Q_{i,t}, q_{j,t}^{inv}, p_{j,t}^0, w_t^e)$ gives the factor demand for capital under the given technology and prices. We assume constant returns to scale production in the consumption goods sector, which implies that $\tilde{c}$ is homogeneous of degree one in $Q_{i,t}$ and the exact quantity which is ordered by a customer becomes irrelevant for $p_{j,t}^{add}$, yielding

$$p_{j,t}^{add} = (1-\eta_j)\frac{\tilde{c}(1, q_0^{inv}, p_{j,t}^0, w_t^e) - \tilde{c}(1, q_{j,t}^{inv}, p_{j,t}^0, w_t^e)}{\tilde{K}_{i,j,t}(1, q_{j,t}^{inv}, p_{j,t}^0, w_t^e)}$$

3.1.4 Production decision and adaptation of labor force

Investment good producers produce output once a month, where for reasons of simplicity lead-times and production times are set to zero. The desired output quantity $\tilde{Q}_{j,t}^{inv}$ in a given month is given by the sum of all orders received during that month. The corresponding labor input is

$$\tilde{\tilde{L}}_{j,t}^{inv} = \frac{\tilde{Q}_{j,t}^{inv}}{\gamma}.$$

Firing costs $c^{fire} \geq 0$ for each worker that is dismissed arise. The level of these costs depends on the prevailing labor market regulations. Expecting such firing costs firms calculate labor-market rigidity costs $c^{rig} \geq 0$ for each worker they hire. The firm adapts the desired size of its labor force in a myopic way based on current cost considerations. In particular,

$$\tilde{L}_{j,t}^{inv} = \begin{cases} L_{j,t-1}^{inv} & \text{if } L_{j,t-1} > \tilde{\tilde{L}}_{j,t}^{inv}, w_t^e < c^{fire} \\ & \quad \text{or } L_{j,t-1}^{inv} < \tilde{\tilde{L}}_{j,t}^{inv}, \gamma p_{j,t}^{inv} - (w_t^e + e_t) < c^{rig} \\ \tilde{\tilde{L}}_{j,t}^{inv} & \text{else} \end{cases}$$

where w_t^e is again the naively expected wage. The first case addressing the issue that a firm will not adjust its workforce to $\tilde{L}_{j,t}^{inv}$ if firing costs are sufficiently high to keep employees in the firm although their labor is currently not needed or the rigidity costs associated with a newly hired worker exceed the current net profit generated by that worker. If neither of those labor market rigidities is binding an investment good producer either posts vacancies for workers with low general skills according to $\tilde{L}^{inv}_{j,t} - L^{inv}_{j,t-1}$ or dismisses workers along $L^{inv}_{j,t-1} - \tilde{L}^{inv}_{j,t}$ using a last-in first-out rule.

Investment good producers might be rationed on the labor market in a sense that they are not able to fill all vacancies they have posted. Hence, the actual size of the workforce in period t might be smaller than the desired one and we have $L^{inv}_{j,t} \leq \tilde{L}^{inv}_{j,t}$. Actual production in period t is given by (1) and if $Q^{inv}_{j,t} < \tilde{Q}^{inv}_{j,t}$ only a fraction $\frac{Q^{inv}_{j,t}}{\tilde{Q}^{inv}_{j,t}}$ of the ordered quantity is supplied to each customer. Production times are not explicitly considered and the quantities are delivered at the point in time when they are produced. At that point in time revenues are received and all wages are paid.

Finally the savings of the firm, $Sav_{j,t}$, are updated as

$$Sav^{inv}_{j,t} = int_t Sav^{int}_{j,t-1} + Q^{inv}_{j,t} p_{j,t} - (w_{j,t} + e_t) L^{inv}_{j,t} - w^{RD}_{j,t} L^{RD}_{j,t},$$

where $w_{i,t}$ and $w^{RD}_{i,t}$ denote the actual average wage rate paid by firm j to production respectively R & D workers and int_t is the short term interest rate to be determined on the credit market. If the debt (i.e. negative savings) to revenue ratio of a firm exceeds a certain threshold the firm goes bankrupt and exits the market.

3.2 Consumption good producers (CGP) and the demand for capital goods

Consumption good producers (CGP), denoted by i, need physical capital and labor to produce the consumption goods. Each CGP uses a capital good of a particular technology $J_{i,t}$ and quality.

The accumulation of physical capital by a CGP follows

$$K_{i,j,t+1} = (1 - \delta) K_{i,j,t} + I_{i,j,t} \tag{3}$$

where $K_{i,j}(0) = 0 \; \forall j$ and $I_{i,j,t} > 0$ only for $j = J_{i,t+1}$. Producers might switch production technology, i.e. $(J_{i,t} \neq J_{i,t+1})$. In this case the stock of investment goods for the abandoned technology becomes obsolete. Incorporating into the model the possibility that certain production technologies become obsolete over time seems important in order to capture the role of general skills with respect to the ability of workers to adapt to new technologies. From an empirical perspective flexibility of that kind of the workforce is often seen as an important factor for employment dynamics.

The average quality of the stock of investment goods $A_{i,t}$ used by CGP i is

$$A_{i,t+1} = \begin{cases} \frac{(1-\delta)K_{i,J_{i,t},t}}{K_{i,J_{i,t},t+1}} A_{i,t} + \frac{I_{i,j,t}}{K_{i,J_{i,t},t+1}} q^{inv}_{J_{i,t+1},t+1} & J_{i,t+1} = J_{i,t} \\ q^{inv}_{J_{i,t+1},t+1} & J_{i,t+1} \neq J_{i,t} \end{cases} \tag{4}$$

As introduced in the general features, every worker w has a level of general skills b^{gen}_w and a level of specific skills $b_{w,j,t}$ for each technology $j \in INV(t)$. The specific skills of worker w for technology j are measured in units of technology specific quality, and they indicate how efficient the technology j is exploited by the individual worker. Building up those specific skills depends on collecting experience by using the corresponding technology in the production process. There is vast empirical evidence for such adjustment processes (see e.g. Argote and Epple (1990)). The shape of the evolution of productivity follows a concave curve, the so-called learning curve, when the organizational productivity is recorded after implementing a new production method or introducing a new good. Concavity in this context means that the productivity rises with proceeding use of the production method or production of the new good, but this increase emerges with a decreasing rate.

This pattern of organizational learning we transfer on the individual level. We assume that the development of individual productivity follows a learning curve. The specific skills are updated once in each production cycle of one month. We assume that updating takes place at the end of the cycle.

A crucial assumption is the positive relationship between the general skills b^{gen}_w of a worker and his ability to utilize his experience. Building up worker's technology specific skills depends on a worker's level of general skills, i.e. his education and the other abilities which are not directly linked to the particular technology.

Taking account of the relevance of the general skill level, the specific skills of a worker w for technology j is assumed to evolve according to

$$b_{w,j,t+1} = b_{w,j,t} + \chi(b^{gen}_w, B_{i,t}) \cdot (A_{i,t} - b_{w,j,t}) \, . \tag{5}$$

in case of using technology j, otherwise the specific skills in $t+1$ remain on the same level as in the current period. The function χ is increasing in the general skill level of the worker and the average specific skill level $B_{i,t}$ present in the firm. Note that this formulation captures the fact that in the absence of technology improvements marginal learning curve effects per time unit decrease as experience is accumulated and the specific skills of the worker approaches the current technological frontier.

Considering the whole workforce of a particular firm the average specific skill level reads

$$B_{i,t} = \frac{1}{L_{i,t}} \sum_{w \in W_{i,t}} b_{w,j,t},$$

where $j = J_{i,t}$, $W_{i,t}$ denotes the set of employees of a CGP i at t, and $L_{i,t} =\mid W_{i,t} \mid$.

The production technology in the consumption goods sector is represented by a Cobb-Douglas type production function with complementarities between the quality of the investment goods and the specific skills of employees for using that type of technology. The productivity of labor (or capital) is determined by the minimum of the average quality of physical capital and the average level of relevant specific skills of the workers. Capital and labor input is substitutable with a constant elasticity and we assume constant returns to scale. Accordingly, output for a CGP is given by

$$Q_{i,t} = \min[B_{i,t}, A_{i,t}] \times L_{i,t}^{\alpha} K_{i,J_{i,t}t}^{\beta}, \tag{6}$$

with $\alpha + \beta = 1$.

We now turn to the three decisions a consumption good producer has to make in his role as buyer on the capital goods market: (1) He needs to decide which particular technology he wants to use, (2) the desired amount by which the stock of capital goods (and labor) should be adapted needs to be determined, (3) the actual production quantity of the consumptions good has to be determined based on the adjustment of the stocks of physical capital and labor that could be realized on the capital goods and the labor market. Strictly speaking the last of these decisions could be assigned to the role of the consumption good producer as a supplier on the consumption goods market, but since this decision is very closely related to decision (2) we treat it here.

3.2.1 Technology choice

The CGP decides every month which particular technology from $INV(t)$ he wants to use in the next period. One alternative is to keep the currently used technology $J_{i,t}$ and to invest in machines of this type of technology. The consumption good producer knows that the quality $q_{j,t}^{inv} > 0$ with $j \in INV(t)$ of these machines is improved over time due to R & D activities by the capital goods producers as sketched in section 3.1.2. The second alternative is to invest in a new technology. In this case the old capital stock becomes obsolete. The CGP decides in favor of the cost-saving alternative. If there are several new technologies which are all cost-saving in comparison to the currently used technology the CGP will choose the most cost-saving technology. In order to make this decision the CGP has to estimate production costs under the use of the different available choices of technology. In order to calculate these different estimated production costs the firms have to determine the stocks of physical capital and labor they would choose for each of the available technologies. Therefore, desired investment levels have to be determined as part of the technology choice problem.

Investments in the technology that is currently used:
Firms aim to realize a capital to labor ratio according to the standard rule for CES production functions. That is a ratio of quantity to price of the two factors proportional to the corresponding intensity parameter. Accordingly,

$$\frac{\tilde{K}_{i,t}}{p^{inv}} / \frac{\tilde{L}_{i,t}}{w_t^e} = \frac{\beta}{\alpha}.$$

Taking into account the production function (6) this yields under the assumption of positive investments

$$\begin{aligned}\tilde{\tilde{K}}_{i,t} &= \frac{(\beta w_t^e)^\alpha \tilde{Q}_{i,t}}{(\alpha p^{inv})^\alpha \min[A_{i,t}, B_{i,t}]} \\ \tilde{\tilde{L}}_{i,t} &= \frac{(\alpha p^{inv})^\beta \tilde{Q}_{i,t}}{(\beta w_t^e)^\beta \min[A_{i,t}, B_{i,t}]}\end{aligned}$$

and if $\tilde{\tilde{K}}_{i,t} \geq (1-\delta)K_{i,t-1}$ the desired capital and labor stocks read

$$\begin{aligned}\tilde{K}_{i,t} &= \nu_i(1-\delta)K_{i,t-1} + (1-\nu_i)\tilde{\tilde{K}}_{i,t} \\ \tilde{L}_{i,t} &= \nu_i L_{i,t-1} + (1-\nu_i)\tilde{\tilde{L}}_{i,t}.\end{aligned}$$

The parameter $\nu_i \in [0,1)$ describes the inertia of firms in changing the levels of their production factors over time. Such inertia can in particular be due to labor market rigidities and hiring and firing costs. If $\tilde{\tilde{K}}_{i,t} < (1-\delta)K_{i,t-1}$, we have

$$\begin{aligned}\tilde{K}_{i,t} &= (1-\delta)K_{i,t-1} \\ \tilde{L}_{i,t} &= \nu_i L_{i,t-1} + (1-\nu_i)\left(\frac{(\tilde{Q}_{i,t}}{((1-\delta)K_{i,t-1})^\beta \min[A_{i,t}, B_{i,t}]}\right)^{1/\alpha}.\end{aligned}$$

Investments in new technology:
The calculation of the anticipated costs in case of a switch to a new technology

$\hat{j}$ is analogous to the procedure described above for the current technology, where we have to set $K_{i,t-1} = 0, A_{i,t} = q^{inv}_{\hat{j},t}$, $\tilde{B} = \frac{1}{L_{i,t}} \sum_{w \in W_{i,t}} b_{w,\hat{j},t}$ and the inertia of factor adaptation is assumed to be zero at the period where the firm switches technologies. The resulting discounted costs over the time horizon T is denoted by $\hat{c}^{new}_{\hat{j}}(\tilde{Q}_{i,t})$.

The technology choice of the CGP now follows directly by comparing the costs of using the old technology and the costs of using the new technology. Thus, the technology

$$J_{i,t} = \begin{cases} = J_{i,t-1} & \min_{\hat{j} \neq J_{i,t-1}}[\hat{c}^{new}_{\hat{j}}(\tilde{Q}_{i,t})] \geq \hat{c}^{old}_{J_{i,t-1}}(\tilde{Q}_{i,t}) \\ = \arg\min_{\hat{j} \neq J_{i,t-1}}[\hat{c}^{new}_{\hat{j}}(\tilde{Q}_{i,t})] & \min_{\hat{j} \neq J_{i,t-1}}[\hat{c}^{new}_{\hat{j}}(\tilde{Q}_{i,t})] < \hat{c}^{old}_{J_{i,t-1}}(\tilde{Q}_{i,t}) \end{cases} \tag{7}$$

is chosen.

3.2.2 Investment in capital goods and labor demand

Note, that in the process of determining its technology choice the CGP also calculates its desired level of labor and investment goods for the cost minimizing production technology. Accordingly, desired capital investment reads

$$\tilde{I}_{i,J_{i,t},t} = \max[0, \tilde{K}_{i,J_{i,t},t} - (1-\delta)K_{i,t}].$$

In case there is a positive demand for investment goods, the CGP places a corresponding order with the capital good producer $J_{i,t}$. With respect to the labor demand vacancies are posted on the labor market if net demand is positive, for negative net demand employees are dismissed according to a last-in-first-out rule.

3.2.3 Production quantity

After a CGP has finished its hiring respectively firing process and its transactions on the capital goods market the actual stocks of capital and labor, $K_{i,t}$ and $L_{i,t}$, as well as its actual average specific skill level $B_{i,t}$ and its actual average quality of investment goods $A_{i,t}$ determine how much the firm will be able to produce in the current period. Due to financial constraints or rationing on the factor markets the obtained quantities might differ from the planned ones. As in the case of capital good producers, available inputs might turn out not to be sufficient to produce the desired quantity, i.e.

$$\tilde{Q}_{i,t} < Q_{i,t} = \min[B_{i,t}, A_{i,t}] \times L^{\alpha}_{i,t} K^{\beta}_{i,t}.$$

In subsection 4.1.3 it will become clear how this might affect deliveries to the malls. In the opposite case with $\tilde{Q}_{i,t} > Q_{i,t}$ the firm has the opportunity to produce more than initially intended. We assume that the firm stores the excess goods as a buffer should it be rationed in the future. Details are given in subsection 4.1.3.

4 Consumption goods market

We assume that consumption goods are sold at malls. The malls are simple representations of local consumption goods markets and for simplicity it is assumed that there is exactly one mall per region. Firms store and offer consumption goods at malls and post quality and price of the good they offer there. Transportation costs from CGPs to malls are considered to be negligible and each consumption good producer might serve the malls in all regions. In general each producer however serves only a subset of the available malls and selection of the set of malls to be served is one of the choices to be made by CGP. Consumers collect information about qualities and prices of the goods offered at their mall and then purchase goods according to their preferences and available stocks. They face costs when going to a mall outside their region but still might do so in order to profit from differences in the quality/price ratio between malls. Figure 3 gives an overview over the decisions to be taken on the consumption goods market and the relevant information flows. In the following subsections we describe the rules governing the behavior of agent with respect to these different decisions.

4.1 Decisions of consumption good producers

The production technology of consumption goods producers and the way a desired production quantity in a given period transforms to actual output has already been described in our treatment of the capital goods market. Here we focus on the firms' selection of malls to be served as well as their decisions about the price at which their product is offered at the selected malls and the way the desired production quantity in a period is determined. Whereas, pricing and quantity decisions are taken once a month the set of malls to be served is reviewed by the firms once a year. Finally, CPGs carry out R & D in order to develop product innovations and to increase the quality of the offered product. Like for capital goods producers the R & D effort is updated once a year.

4.1.1 The firms' mall choice

We turn to the mall choice of the firm. The mall choice is activated once a year. Firms base their mall choice on standard net present value consid-

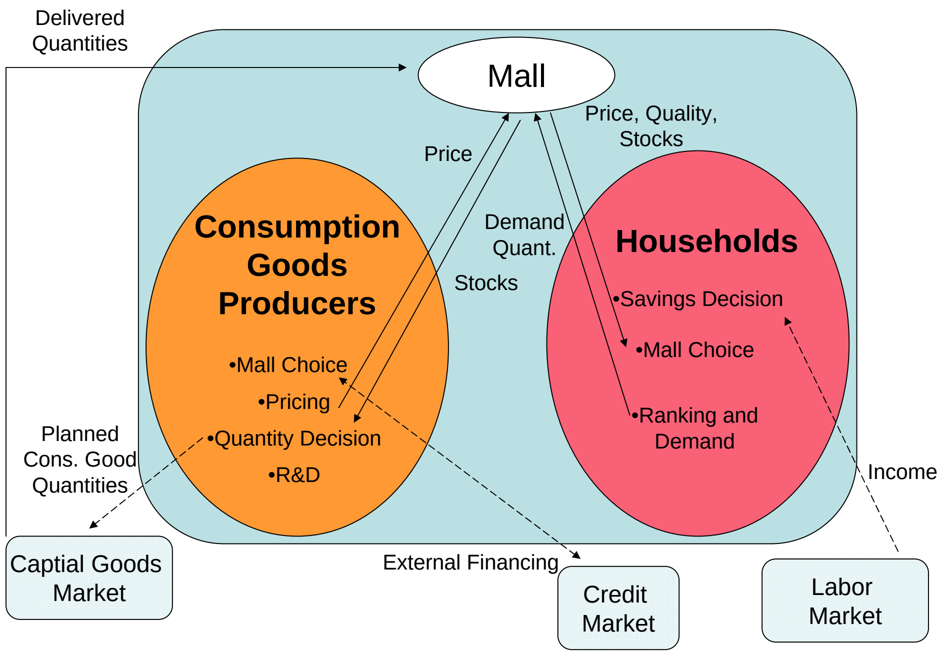

Figure 3: Consumption goods market

erations, where they compare costs from expanding their set of malls they serve with estimated profits to be made by sales in that region. The decision-making process basically consists of three parts.

First, firms consider for each region r the regional consumption expenditures and the competition in that particular region in order to estimate their potential regional sales. To estimate local consumption expenditures the EURACE framework allows to utilize statistical data about the average per-capita income $y_{r,t}$ in a region, its population size P_r and the economy-wide savings quota q_t^{sav}. As only one consumption good exists, though with different quality levels, the statistical data directly leads to an estimation of the regional expenditures for that consumption good:

$$\hat{y}_{r,t}^{cons} = (1 - q_t^{sav}) P_r y_{r,t}$$

Using this kind of estimation rather than directly data of previous consumption expenditures in the region avoids to underestimate the potential for firms in regions where expenditures in the past have been relatively low due to a lack of supply of attractive goods. In order to get the potential regional sales the data on the potential regional expenditures is adjusted by the expected market share $MS^{e}_{t,i,r}$ of firm i. In regions where the firm has no estimate of its potential market share based on detailed market analysis (see below) or previous experience in that region the fair share approach seems the best alternative, which means in our context that if actually $v_{t,r}$ competitors populate a region the firm will expect to obtain $MS^{e}_{t,i,r} = \frac{1}{v_{t,r}+1}$ of the generated revenues (see Beaumont (1991)). If the firm previously did a market analysis for that region then the estimated market share is set equal to this last estimate.

Thus, we get rough estimates for the revenues firm i can realize in a particular region r:

$$R^{loc,e}_{i,r,t} = MS^{e}_{t,i,r}\hat{y}^{cons}_{r,t}.$$

Firms rank regions based on $R^{loc,e}_{i,r,t}$ and, as a second step in the procedure, generate a short list $r^{short} \subset \{1, \ldots, R\}$. The top ten ranked regions could define such a short list. For the regions on the short list the firms instruct the market research entity to test the actual sales potential of the consumption good in the same manner in which they test the sales consequences of potential price changes. Possessing trustworthy data about the expected revenues, $R^{ma,e}_{i,r,t}$, the firms order the regions on the short list r^{short} according to a net present value approach:

$$NPV_{t,i,r} = -p^{inv}_{j,t}\Delta K^{e}_{i,j,r,t} + \frac{R^{ma,e}_{i,r,t} - w^{e}_{t}\Delta L^{e}_{i,r,t} - \delta p^{inv}_{j,t}\Delta K^{e}_{i,j,r,t} - Rent_r}{(1-\rho)},$$

where $\Delta K^{e}_{i,j,r,t}$ and $\Delta L^{e}_{i,r,t}$ denote the additional stock of capital and labor needed to satisfy the estimated demand in region r and $Rent_r$ indicates the costs of running a sales-point in region r.

As a result of the net present value analysis regions/malls are sorted in descending order of their net present value. The firm enters as many of the short listed regions/malls with positive net present value as their financial situation permits.

Considering the effects of financial constraints we assume that an expansion in a particular region takes only place if the estimated market demand can be completely saturated (see for instance Rubinfeld and Hemingway (2005)). If a firm lacks the financial resources to do the necessary investments to saturate the demand in the top ranked region it has to drop the plan to enter the region this time and instead enters the next positive net present value region on the short list for which it has enough resources to do so. If we define that $z^{b}_{t,i,r} = 1$ means that the firm i enters region r and

$z^b_{t,i,r} = 0$ that it does not, the financial reserves of the firm again as $Sav_{i,t}$ and the available credit as $CreditLine_{i,t}$, then we get the following decision rule:

$$z^b_{t,i,r} = \left\{ \begin{array}{ll} 1 & \text{if } Sav^{net}_{i,r,t} > p^{inv}_{j,t} \Delta K^e_{i,j,r,t} \wedge NPV_{i,r,t} > 0, r \in r^{short} \\ 0 & \text{else,} \end{array} \right\}$$

where

$$Sav^{net}_{i,r,t} = Sav_{i,t} + CreditLine_{i,t} - \sum_{l:NPV_{i,l,t} > NPV_{i,r,t}} z^b_{i,l,t} p^{inv}_{j,t} \Delta \hat{K}_{i,j,r,t}.$$

Note, that we have a link to the financial and credit market here as firms may seek for external funding in order to accomplish their market penetration plans. As the result of this algorithm the firm obtains the list $M_{i,t} \subset \{1, \ldots, R\}$ of regions it will serve in period t.

4.1.2 Pricing

Consumption good producer might charge different prices for their product in different regions based on different local demand conditions. In order to decide whether to increase or decrease the price $p_{i,r,t}$ charged in region r firm i employs a standard approach from the management literature on pricing, the so-called 'break-even analysis' (see Nagle (1987)). The break-even formula determines at what point the change in sales becomes large enough to make a price reduction profitable and at what point the decrease in sales becomes small enough to justify a rise in the price. Basically, this managerial pricing rule corresponds to standard elasticity based pricing.

Applying the break-even rule to our setting leads to the following specifications. Denote by $\pi_{i,r,t}$ the profits of a consumption good producer i at time t at mall r

$$\pi_{i,r,t-1}(p_{i,r,t-1}) = (p_{i,r,t-1} - \bar{c}_{i,t-1}) D_{i,r,t-1}$$

where $\bar{c}_{i,t-1}$ denotes unit costs in production of firm i in the previous period and $D_{i,r,t}$ is the quantity of goods of producer i demanded in region r in period $t-1$.

In order to estimate the effects of a price change an independent market research entity provides the firm with updated information on the expected output change following price changes of $(1+\epsilon)$ and $(1-\epsilon)$. This market research entity each period randomly picks a sample of consumers, and confronts them with the alternative prices and registers the changes in the purchasing decisions. Based on this expected demands $D^e_{i,r,t-1}((1+\epsilon)p_{i,r,t-1})$

and $D^e_{i,r,t-1}((1-\epsilon)p_{i,r,t-1})$ are determined and the firm calculates the corresponding expected profits. If any of the price changes lead to an increase in expected profits then the price is adjusted accordingly:

$$p_{i,r,t} = \begin{cases} (1+\epsilon)p_{i,r,t-1} & \text{if } \pi^e_{i,r,t-1}((1+\epsilon)p_{i,r,t-1}) > (1+\theta_i)\pi_{i,r,t-1} \\ (1-\epsilon)p_{i,r,t-1} & \text{if } \pi^e_{i,r,t-1}((1-\epsilon)p_{i,r,t-1}) > (1+\theta_i)\pi_{i,r,t-1} \\ p_{i,r,t-1} & \text{else,} \end{cases}$$

where $\theta_i > 0$ is a strategy parameter expressing the inertia of the firm in adapting prices.

Once the firm has determined the updated prices $p_{i,r,t}$ for all regions r where it offers its goods, the new prices are sent to the regional malls and posted there for the following period.

4.1.3 Quantity choice

Every CGP keeps a stock of its products at every regional mall where it offers goods. A producer checks once every period whether any of the stocks it keeps at different malls have to be refilled. To that end the firm receives messages from all the malls it serves reporting the current stock level. Taking this information into account, the firm i has to decide whether and on what scale it restocks the supply. According to our suggestion of using standard managerial methods wherever it is applicable, we employ a standard inventory rule for managing the stock holding. For reasons of simplicity we ignore setup costs that arise for each delivery to a mall. We denote by $C^{inv}_{i,r}$ costs of holding one unit of the good in the inventory for one period and by $\tilde{\Phi}_{i,r,t}(D) : [0,\infty) \mapsto [0,1]$ the estimated distribution function of the demand for the good of firm i at the mall in region r, where the estimation is based on demands reported by the mall in the previous T periods. Furthermore, $SL_{i,r,t}$ is the level of the stock of firm i at the mall in region r at the day in period t when the stock is checked. Then, standard results from inventory theory suggest that the firm should choose its desired replenishment quantity for region r according to the following simply rule (see Hillier and Lieberman (1986)):

$$\tilde{D}_{i,r,t} = \begin{cases} 0 & SL_{i,r,t} \geq Y_{i,r,t} \\ Y_{i,r,t} - SL_{i,r,t} & SL_{i,r,t} < Y_{i,r,t}, \end{cases}$$

where $Y_{i,r,t}$ is the smallest value $Y \geq 0$ that satisfies

$$\tilde{\Phi}_{i,r,t}(Y) \geq \frac{p_{i,r,t} - (1-\rho)\bar{c}_{i,t-1}}{p_{i,r,t} + C^{inv}_{i,r}},$$

where again $\bar{c}_{i,t-1}$ denotes unit costs in production of firm i in the previous period. The sum of the orders received by all malls becomes

$$\tilde{D}_{i,t} = \sum_{r \in M_{i,t}} \tilde{D}_{i,r,t},$$

where $M_{i,t}$ gives the set of all regions served by firm i in period t.

To avoid excessive oscillations of the quantities $\tilde{Q}_{i,t}$ that the firm desires to produce in period t, the time-series of total quantities required by the different malls ($D_{i,t}$) is smoothed. A central buffer of goods $CS_{i,t}$ is introduced and in case of strong downward outliers of demand actual production quantity is adapted at a lower rate and the central buffer is filled. In particular,

$$\tilde{Q}_{i,t} = \max[\bar{D}_{i,t}, \tilde{D}_{i,t} - CS_{i,t-1}]$$

with

$$\bar{D}_{i,t} = 0.8 \frac{1}{T} \sum_{\tau=1}^{T} \tilde{D}_{i,t-\tau}.$$

As explained in subsection 3.2.3 the CGP might be rationed on factor markets and actual production quantities might be below the desired level. Also in such cases the central buffer might be used to smooth deliveries. The actual delivery from firm i to the mall in region r in period t reads

$$D_{i,r,t} = \min\left[1, \frac{Q_{i,t} + CS_{i,t-1}}{\tilde{D}_{i,t}}\right] \tilde{D}_{i,r,t}.$$

Accordingly, the stock of the central buffers follows

$$CS_{i,t} = CS_{i,t-1} + Q_{i,t} - \sum_{r \in M_{i,t}} D_{i,r,t}, \quad CS_{i,0} = 0.$$

Finally, it should be noted that in periods where firms acquire positive quantities of the investment goods some time delay between ordering and receiving the good might arise due to the fact that investment goods producers deliver only once a month. Production takes place at the point in time when the ordered investment goods arrive. As in the capital goods sector production times of consumption goods are not explicitly taken into account and the produced quantities are delivered on the same day when production takes place. The local stock levels at the malls are updated accordingly. Wages for the full month are paid to all workers at the day when the firm updates its labor force (i.e. the activation day of the capital and labor investment decision of the CGP). Investment goods are paid at the day when they are delivered.

4.1.4 R&D investments

The quality of the consumption good produced by firm i, denoted by $q_{i,t}^{cons}$ can be increased by investment in product innovation. The dynamics of R & D in the consumption good sector is very similar to the one in the capital goods sector.

Denote by $L_{i,t}^{RD,cons}$ the number of R&D workers employed by CGP i at time t, then the probability that the innovation project is successfully completed in a given month is $\min[1, \gamma^{cons} L_{i,t}^{RD,cons}]$, where $\gamma^{cons} > 0$ is a parameter expressing the efficiency of R&D activities in the consumption goods sector. If a project is successfully completed this leads to a change product quality by $\Delta q_{i,t}^{cons} = q_{i,t}^{cons} \max[0, \bar{q}_{innov}^{cons} + \vartheta]$ where $\bar{q}_{innov}^{cons} > 0$ is the average percentage-increase in product quality induced by an innovation and ϑ is stochastic with mean zero. In the following period month the firm starts a new innovation project.

The number of R&D employees is reviewed and updated by the CGP once a year in the same way investment goods producers update their R & D personnel (see subsection 3.1.2). Again, we assume that R&D employees must have the highest level of general skills.

Calculating the additional revenue $\Delta \hat{R}_{i,t}$ CGPs can use information they receive from their market research. They estimate the revenue $\hat{R}_{i,t-1}$ that would have been generated in the previous period if the quality of the product would have been $q_{i,t-1}^{cons}(1 + \bar{q}_{innov}^{cons})$ instead of $q_{i,t-1}^{cons}$. The estimated additional revenue stream is then given by

$$\Delta \hat{R}_{i,t} = \frac{1 - \rho^T}{1 - \rho} (\hat{R}_{i,t-1} - R_{i,t-1}).$$

Analogous to the case of investment goods producers the desired number of R & D employees is then given by

$$\tilde{L}_{j,t}^{RD,cons} = \kappa_i^{cons} (\gamma^{cons} \Delta \hat{R}_{i,t} - w_t^{RD,e}), \tag{8}$$

where the parameter $\kappa_i^{cons} \geq 0$ again is a strategy parameter of the firm expressing its propensity to invest in innovative efforts.

4.1.5 Financing

Denoting the actual average wage rate paid by firm i in period t to general respectively high skill workers by $w_{i,t}$ and $w_{i,t}^{RD}$ the total expenditures of firm i in period t are given by

$$Exp_{i,t} = L_{i,t} w_{i,t} + L_{i,t}^{RD} w_{i,t}^{RD} + I_{i,J_{i,t},t} p_{J_{i,t},t}^{inv} + \sum_{r \in M_{i,t}} Rent_r.$$

On the other hand, the firm receives revenues from sales in all the malls it served in the previous period:

$$R_{i,t-1} = \sum_{r \in M_{i,t-1}} (SL_{i,r,t-1} + D_{i,r,t-1} - SL_{i,r,t}) p_{i,r,t-1}.$$

Accordingly, savings of the firm are updated as

$$Sav_{i,t} = int_t Sav_{i,t-1} + R_{i,t-1} - Exp_{i,t},$$

where int_t is the short term interest rate to be determined on the credit market.

In general, all expenditures for labor and capital investments might be financed by own revenues ($R_{i,t-1}$), savings ($Sav_{i,t-1}$)or, if available, by bank credits or via the financial market. We do not explicitly treat financing decisions or financial constraints in this document, since in the EURACE framework these issues are dealt in the credit and financial market modules. Financial constraints and inability to obtain sufficient financing for planned investment might however be another reason that a firm cannot obtain the desired quantities on the labor market. If the debt (i.e. negative savings) to revenue ratio of a firm exceeds a certain threshold the firm goes bankrupt and exits the market. Again, details of this process are provided in the description of the credit market. An exiting firm inherits its stock of physical capital to some new entrant but all current workers of the firm become unemployed.

4.2 Demand for consumption goods

Once a month, when they receive their income, consumers allocate their cash at hand to savings and consumption. It is assumed that every consumer once a week visits one mall to purchase consumer goods. Among all consumers who visit the same mall on the same day, randomly an order of their visits to the mall is established. In the following part the decisions of consumers are considered. Consumers first must decide which mall to visit. They then sample qualities and prices and available stocks of the goods offered at the mall and make their purchasing decisions based on this information and the budget they have allocated for consumption.

4.2.1 The savings decision

Agent's decision making concerning consumption is separated into two parts: depending on the available cash, that is the current income from factor markets plus assets carried over from the previous period, the consumer sets the budget which he will spend for consumption and consequently determines the remaining part which is saved. Then the consumer decides where to go for shopping and which goods to buy.

Our decision rule for the determining the savings, i.e. the first decision to be taken, is based on the work of Deaton (1991). Deaton examines the saving behavior of impatient consumers when they are not permitted to borrow. In a scenario with independent and identically distributed income draws, he obtains a consumption function depending on cash on hand, which has the following characteristics: there exists a critical value of cash on hand. When the available liquidity is below this critical value the whole cash on hand will be spent. In the opposite case the agent will save a part of his cash on hand. The savings depend on cash as well as uncertainty over income. The assets act like a buffer stock which protect consumption against bad income draws.

We assume a stepwise linear approximation of the consumption rule derived by Deaton (1991, 1992). At the beginning of period t, a consumer k decides about the budget $B_{k,t}^{cons}$ that he will spend. In period t the agent receives an income $Inc_{k,t}$ and holds assets $Ass_{k,t}$. Thus cash on hand is denoted by $Liq_{k,t}^{Avail} = Ass_{k,t} + Inc_{k,t}$. The assets evolve according to

$$Ass_{k,t} = (1 + int_t)(Liq_{k,t-1}^{Avail} - B_{k,t-1}^{cons})$$

where int_t is the interest rate for short-term investments. Note, that while we treat the interest rate as exogenous here, in the fully fledged EURACE framework where financial and credit markets are included, the interest rate would become endogenous.

The consumer sets his consumption according to the following consumption rule

$$B_{k,t}^{cons} = \begin{cases} Liq_{k,t}^{Avail} - \kappa(\sigma_t^{Inc})(Liq_{k,t}^{Avail} - \Phi \cdot Inc_{k,t}^{Mean}) & \text{for } Liq_{k,t}^{Avail} > \Phi \cdot Inc_{k,t}^{Mean} \\ Liq_{k,t}^{Avail} & \text{else,} \end{cases}$$

where $\Phi \leq 1$ is a parameter, and $Inc_{k,t}^{Mean}$ is the mean individual income of an agent over the last, say, T periods. By definition the saving propensity fulfills $0 < \kappa < 1$. We assume that $\kappa'(\sigma_t^{Inc}) > 0$ where σ_t^{Inc} is the standard deviation of income distribution in t. Thus macroeconomic uncertainty over income drives the savings propensity. Details about the way households accumulate assets in EURACE are given in the description of the EURACE financial and credit market.

The implications of this consumption rule are as follows: if an agent has a current cash on hand that is below the fraction Φ of mean income, he spends all available liquidity and nothing is saved. If cash on hand exceeds

$\Phi \cdot Inc^{Mean}_{k,t}$, the agent saves a fixed fraction in order to build up a buffer stock for bad times. How much of liquidity is saved depends on income uncertainty.

The part of cash at hand that is not saved is used as the consumption budget for that month. Each consumer goes shopping once every week, so the monthly budget is equally split over the four weeks. Parts of the weekly budget that are not spent in a given week are rolled over to the consumption budget of the following week. This yields a consumption budget $B^{cons}_{k,week_t}$ for each week in period t.

4.2.2 Households' mall choice

We suggest the following decision rule with respect to the mall choice. Every week with a given probability $prob^{loy}$ a consumer visits the same mall as the week before. With probability (1-$prob^{loy}$) he compares the closest $m^{sub} \geq 1$ malls to decide which mall to go to. This yields a list $l^{mall}_{k,t} \subset R$ of malls, where R again is the set of all regions. The consumer obtains information about average product quality and prices in the malls in $l^{mall}_{k,t}$ as well as the rectilinear distances and ranks the malls based on a weighted average of distance and quality/price ratio. Denoting by $q^{av}_{r,t}$ and $p^{av}_{r,t}$ average quality and price in the mall in region r and by $\bar{q}_{k,t-1}$ the average quality of the goods consumed by k in the previous period $t-1$ we define

$$U_{k,m}(r_k, r, q^{av}_{r,t}, p^{av}_{r,t}) = v_k(q^{av}_{r,t}, p^{av}_{r,t}, \bar{q}_{k,t-1}) - \zeta_k dist_{r_k,r},$$

where $v_k(.)$ describes the 'utility' of a good with price $p^{av}_{r,t}$ and quality $q^{av}_{r,t}$ for consumer k in a logit-choice consumer model (see subsection 4.2.3). The parameter $\zeta_k \geq 0$ determines how strongly the mall choice is determined by geographical considerations.

Following the well established logit approach to individual choice this leads to the probabilities

$$Prob_{k,r,t} = \frac{\text{Exp}[\lambda^{mall}_k U_{k,m}(r_k, r, q^{av}_{r,t}, p^{av}_{r,t})]}{\sum_{r' \in l^{mall}} \text{Exp}[\lambda^{mall}_k U_{k,m'}(r_k, r', q^{av}_{r',t}, p^{av}_{r',t})]}$$

for choosing a particular mall, where $\lambda_k > 0$ is the intensity of choice for consumer k in the mall choice decision.

4.2.3 The consumption decision

Having selected a mall the consumer collects information about the range of goods provided. He receives information about prices, quality levels of goods and inventories.

He ranks the firms based on the collected information and his preferences. Sometimes the number of firms offering goods in a certain outlet could be very large. In such a case he does not rank all available firms rather he chooses a set of firms randomly. On the basis of his ranking the consumer sets the demand and quantities which he wants to buy in the mall.

In the Marketing literature it is standard to describe individual consumption decisions using logit models. These models represent the stochastic influence of factors not explicitly modelled on consumption decisions and the power of these models to explain real market data has been well documented (see e.g. Guadagni and Little (1983)). Therefore, we also rely on a model of that kind here. We assume that a consumer k decides which good to buy based on the utility values he attaches to the different choices he is aware of. Denote by $G_{k,week_t}$ the set of producers whose goods consumer k has sampled in week $week_t$ of period t and where a positive stock is available at the attended mall. Then, utility of each consumption good $i \in G_{k,week_t}$ in that sample is given by

$$v_k(q_{i,t}, p_{i,t}, \bar{q}_{k,t-1}) = \varsigma_k^{qual} q_{i,t} + \varsigma_k^{rel} \ln\left(\frac{q_{i,t}}{\bar{q}_{k,t-1}}\right) - p_{i,t},$$

where $\bar{q}_{k,t-1}$ is again the average quality of the goods consumer k has consumed in $t-1$. The consumer also has the option to buy none of the goods in his sample and the utility value associated with that choice is

$$v_k^{none}(\bar{p}_{k,t-1}, \bar{q}_{k,t-1}) = \varsigma_k^{qual} \bar{q}_{k,t-1} - \bar{p}_{k,t-1},$$

where $\bar{p}_{k,t-1}$ is the average price of the goods consumer k has consumed in $t-1$.

The consumer selects one good $i \in G_{k,week_t}$, where the selection probability for i reads

$$Prob_{k,i,t} = \frac{\mathrm{Exp}[\lambda_k^{cons} v_k(q_{i,t}, p_{i,t}, \bar{q}_{k,t-1})]}{\varsigma_k^{none} \mathrm{Exp}[\lambda_k^{cons} v_k^{none}(\bar{p}_{k,t-1}, \bar{q}_{k,t-1})] + \sum_{i' \in G_{k,week_t}} \mathrm{Exp}[\lambda_k^{cons} v_k(q_{i',t}, p_{i',t}, \bar{q}_{k,t-1})]}.$$

The purpose of the term $\ln\left(\frac{q_{i,t}}{\bar{q}_{k,t-1}}\right)$ in the utility and the option for non-consumption is to incorporate aspiration level effects on the consumer side, in a sense that the utility of a certain product quality goes down if the household has already consumed goods of that quality in the past, and that stagnant price-quality combinations might facilitate postponement of consumption by households. Such a framework should allow for real effects of process and product innovations on total output. Furthermore, the demand effect of the two types of innovation are not identical.

Once the consumer has selected a good he spends his entire budget $B^{cons}_{k,week_t}$ for that good if the stock at the mall is sufficiently large. In case the consumer cannot spend all his budget on the product selected first, he spends as much is possible, removes that product from the list $G_{k,week_t}$, updates the logit values and selects another product to spend the remaining consumption budget there. If he is rationed again, he spends as much as possible on the second selected product, rolls over the remaining budget to the following week and finishes the visit to the mall.

5 Labor market

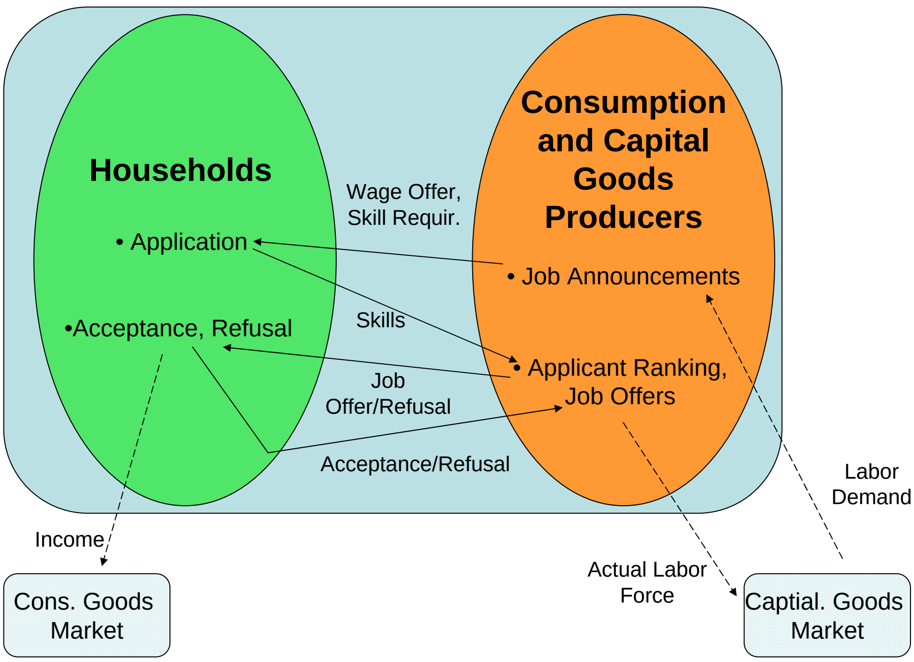

Figure 4: Labor Market Interaction

5.1 Labor demand

Labor demand is determined in the capital and consumption goods market, see sections 3 and 4. Both, the capital and the consumption goods producers need workers for the production of the capital resp. the consumption good as well as for research and development.

The capital as well as the consumption good producers hire only the highest generally skilled (b^{gen}_{max}) workers for R & D, ($LD^{RD,inv}_{j,t}$ and $LD^{RD,cons}_{i,t}$), respectively. For production capital good producers hire only workers of the lowest general skill level (b^{gen}_1), see section 3.1.1. In this respect consumption good producers are different from capital good producers as they hire workers with general skill levels $b^{gen} \in \{1, 2....b^{gen}_{max}\}$ and technology specific skill levels for production, see 3.2.1.

If the firms plan to extend the production or to increase the likelihood for a successful innovation they post vacancies and corresponding wage offers. The wage offer $w^O_{i,t}$ corresponds to the wage that had to be paid the last time a worker was hired. In case of dismissals we use a rule that employees with lowest specific skills are dismissed first.

5.2 Labor supply

Job seekers consist of a randomly determined fraction ϕ of employed workers who search on-the-job and the unemployed.

Workers seeking for jobs do not distinguish between the capital and the consumption goods producers. A worker k only takes the posted wage offer into consideration and compares it with his reservation wage $w^R_{k,t}$. A worker will not apply at a firm that makes a wage offer which is lower than his reservation wage. The level of the reservation wage is determined by the current wage if the worker is employed, and in case of an unemployed by his adjusted past wage. That is an unemployed worker will reduce his reservation wage with the duration of unemployment.

When a worker applies he sends information about his general as well as his specific skill level to the firm. We use a discrete classification of general and specific skills.[2]

5.3 Matching algorithm

According to the procedures described in 3 and 4 each firm reviews once a year whether to post vacancies for R & D jobs and consumption goods

[2]Following the International Adult Literacy Survey five general skill groups seems to be a reasonable choice.

producers also review once a month whether to post vacancies for production workers. In case a firm posts vacancies for R & D and for production workers on the same day transactions for the two vacancies are processed independently from each other. Vacancies stay posted only for a single day and all transactions associated to a vacancy take place on that day. Job seekers check for vacancies every day. The matching between vacancies and job seekers works in the following way:

Step 1: The firms post vacancies for R&D or for production jobs including wage offers and general skill requirements.

Step 2: Every job seeker extracts from the list of vacancies those postings to which he fits in terms of his reservation wage and general skill endowment.

Job seekers rank the suitable vacancies. The vacancy which offers the highest wage is ranked on position one and so on. If the wage offers that come with the posting are equal, vacancies are ranked by chance.

Step 3: Every firm ranks the applicants. Every applicant on the application list for R&D jobs has the general skill level b^{gen}_{max}. Hence the applicants with skill level b^{gen}_{max} are distributed to the lists by chance.

With respect to the other list, applicants with higher general skill b^{gen} levels are ranked higher. If there are two or more applicants with equal general skill levels, but different specific skill levels, the applicant with the higher specific skill level for the technology j currently used by the hiring firm i is ranked higher. If both skill levels of two or more applicants are equal they are ranked by chance.

Firms send job offers to as many applicants going down their ranked application list as they have vacancies to fill.

Step 4: Each worker ranks the incoming job offers corresponding to his preference list. Each worker accepts the highest ranked job offer at the advertised wage rate. After acceptance a worker refuses all other job offers and outstanding applications.

Step 5: Vacancies' lists and applications' lists are adjusted for filled jobs. If a firm received refusals, these applicants are dropped from the list of applicants.

If all vacancies (R&D and/or production) of a firm have been filled the firm refuses the other applicants and the algorithm for this firm ends.

Step 6: If a firm has at least $\bar{v} > 0$ vacancies after the hiring process it raises the wage offer by a fraction φ_i such that $w^O_{i,t+1} = (1 + \varphi_i)w^O_{i,t}$.

If an unemployed job seeker did not find a job he reduces his reservation wage by a fraction ψ_k, that is ($w^R_{k,t+1} = (1 - \psi_k)w^R_{k,t}$). There exists a lower bound to the reservation wage w^R_{min} which may be a function of unemployment benefits, opportunities for black market activity or the value of leisure. If a worker finds a job then his new reservation wage is the actual wage, i.e. $w^R_{k,t} = w_{i,t}$. Go to step 1.

This cycle is aborted after n-times even if not all firms may have satisfied their demand for labor. As discussed above this might lead to rationing of firms on the labor market and therefore to deviations of actual output quantities in a period from the planned quantities.

6 Exit and entry and dynamics of firm behavior

Due to the structure of the rules that govern the behavior of firms and households the actions of the agents change over time in response to their economic environment. Concerning the investment goods and consumption goods producers several key parameters determine the way they react to the information they receive about their environment. For an investment good producer j the key strategy parameters are

- η_j: percentage of value of quality increase passed to customer (determines aggressiveness of pricing).
- κ^{inv}_j: propensity to invest in innovative efforts.
- φ_j: speed of raising wage offers if rationed on the labor market.

Similarly, for a consumption goods producers we have

- θ_i: inertia in adjusting prices.
- κ^{inv}_i: propensity to invest in innovative efforts.
- φ_i: speed of raising wage offers if rationed on the labor market.

In the current formulation of the model these key strategy parameters of firms are assumed to be constant over time. It is planned to extend the framework by allowing adjustment of these strategy parameters according to standard individual and social learning rules as surveyed in van der Hoog and Deissenberg (2007a).

On the level of the firm population changes in the distribution of the strategy parameters may arise through a simple exit and entry process. If a firm goes bankrupt (see 4.1.5) and exits the market it is replaced by an entering firm that inherits the stock of physical capital of the exiting firm but adopts the values of its strategy parameters from some surviving firm in the market, where the probability to imitate a firm increases with its past profits. Hence, on an aggregate level there is some selection pressure towards profitable constellations of the strategy parameters.

7 Conclusion

We described the modelling assumptions for the capital goods, consumptions goods, and the labor market of the EURACE model. In addition to the markets spelled out here, EURACE will also host an credit and a financial market. The interfaces between those markets were pointed at.

As mentioned in the introduction, we start the implementation process by implementing in FLAME a simplified version of the full model described here. Proceeding that way allows us to first test several basic parts of our framework and to adapt the model where necessary. The simplified model is described in Appendix A. A first implementation of that model has been completed and is currently tested.

Upcoming is the implementation of gradual extensions of the simplified model in FLAME aiming at the incorporation of the different economic mechanisms described in this document. This will leaf to a simulation platform which will eventually allow us to study the properties or our model and do policy simulations. Once, the appropriateness of the capital good, consumption good, and the labor market model has been extensively tested all parts will be integrated into the fully fledged EURACE framework.

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Appendix A

In this section of the Appendix we describe the simplified version of the model that will be implemented in the FLAME framework as a first step towards the full implementation of the macroeconomic simulation platform. Although a number of important feedbacks and effects are missing in this implementation the implementation can not only be used to check the working of several key parts of the model but also is already sufficiently rich to address some policy issues related to the effects of changing the distribution of general skills in the workforce or the speed of technological change in the investment goods sector.

A.1 General features

In the reduced version of the model only the consumption goods sector, the labor market and the interaction between the two is explicitly modelled. There is no explicit R & D sector and technological change is exogenous. Nevertheless, technical change, in the sense of firms being able to exploit existing technological options, is endogenous. Furthermore, no market research is carried out in the base version and all behavioral rules where such data is used in the full model have to be adapted accordingly. In what follows we describe the deviations from the full model using the same structure as was used to describe the full model. Aspects of the model that are not mentioned stay unchanged compared to the description given in the main body of this document.

Since the capital goods sector is no longer present in the model, the set of agent types and roles reads as follows:

Active Agents:

- Households
  - Consumption Goods Market: Role of Buyer
  - Labor Market: Role of Worker
- Consumption Goods Producers
  - Consumption Goods Market: Role of Seller
  - Labor Market: Role of Employer

Passive Agents:

- Investment Goods Producers

  - Investment Goods Market: Role of Seller (at given prices), distribution of earning to households

- Malls

  - Consumption Goods Market: Information Transfer between Consumption Goods Producers and Households

A.2 Capital goods market

In the reduced version of the model there exists only a single type of technology for investment goods. The investment good is offered with infinite supply. The quality of the investment good q_t^{inv} increases over time due to a stochastic process. Every period the quality is increased with probability $\gamma^{inv} \in (0,1)$ and in case of an increase the quality of the offered good changes by a fixed percentage Δq^{inv}.

The price of the investment good $p^{inv} > 0$ is assumed to be linked to the level of quality, so that a rise of quality leads to a proportional increase of p^{inv}. Although capital goods producers are not explicitly modelled the amounts paid for investment goods are channelled back into the economy. Revenues accruing with the investment good producer are distributed in equal shares among all households in order to close the model. Thus, it is assumed that all households own equal shares of the fictitious capital goods producer.

Since there is only one investment goods technology consumption goods producers do not have to make any technology choice decisions. Investments in capital goods and labor demand are determined according to the rule described for the full model.

Furthermore, in the first implementation credit constraints are ignored. As a next step credit constraints are incorporated into this version of the model in a very simple way and will still not be linked to an explicit credit market model. Available credit is proportional to the net worth of the firm and we have

$$CreditLine_{i,t} = CreditRatio \max[0, Sav_{i,t-1} + K_{i,t-1}].$$

If planned expenditures exceed firm savings plus credit, i.e. if

$$p^{inv}(\tilde{K}_{i,t} - (1-\delta)K_{i,t-1}) + w_t^e \tilde{L}_{i,t} + \sum_{r \in M_{i,t}} Rent_r \geq Sav_{i,t} + CreditLine_{i,t},$$

then the firm reduces it desired levels of capital and labor such that this constraint is satisfied.

Accordingly, consumption goods producers might be rationed on the credit market as well as on the labor market. Actual output quantities are determined in the same way as in the full model.

A.3 Consumption goods market

Also the decisions determining mall and price choices have to be altered in order to avoid the use of market research data. Concerning mall choice it is simply assumed that all consumption good firms serve all regions, i.e. $M_{i,t} = \{1, \ldots, R\}$ for all i. Pricing is carried out in the same spirit as in the full model. As pointed out before the break-even rule for pricing that is used in the full model would under full information about the individual demand function correspond to standard markup pricing based on the elasticity of demand for goods of producer i. In the absence of market research data all firms are assumed to have constant expectations $\varepsilon_i^e < -1$ of the elasticity of their demand and then set the price according to the standard rule

$$p_{i,t} = \frac{\bar{c}_{i,t-1}}{1 + 1/\varepsilon_i^e},$$

where $\bar{c}_{i,t-1}$ denotes unit costs in production of firm i in the previous period. Quantity choices are made as described for the full model. R & D activities of the consumption goods producers are not explicitly considered in the reduced version and therefore no R & D workers are hired. The quality of the consumption goods offered by the different producers stays constant over time with $q_{i,t} = q_{i,0}\ \forall t$. Behavioral rules of households are not changed compared to the full model, however since increases in the quality of the consumption goods are no longer part of the model, the term in the utility describing households preferences for relative quality is always equal to zero.

A.4 Labor market

The working of the labor market is not changed compared to the full model. Note however that due to the absence of an explicit R&D sector there is no labor market for R&D workers. Since there is only one production technology in the reduced version of the model, specific skills acquired for that technology can always be used after a transfer to a different firm.

Appendix B

Timing of events

This list gives an overview over the periodicity of events in the markets treated in this paper.

B.1 Calender time driven

- Weekly
  - Consumer decides upon outlet mall
  - Consumer ranks offered products and determines quantity
- Monthly
  - Savings decision by households
  - Technology choice by consumption goods producers
  - Price adaption for consumption goods
  - Production quantity determination by consumption goods producers
  - Investment in capital goods and labor demand by consumption goods producer
  - Production quantity determination by capital good producers
  - Labor demand by capital good producers
- Yearly
  - Outlet choice of consumption goods producers
  - R&D investments of capital and consumption goods producers
  - Labor demand for R&D personnel by capital good and consumption good producers

B.2 Event-driven

- Quality improvement of capital good
  - Pricing of capital goods producer
  - Updating of estimated revenue increase due to a successful innovation.

- Quality improvement by consumption goods producers
  - Price adaptation for consumption goods

Appendix C

List of variables and parameters

Generally, the symbol ˜ is used to indicate desired values of a certain variable, whereas the superscript ^{e} indicates an estimated value of a variable. Desired and estimated values of variables that occur in the text are not listed separately here.

C.1 General

VARIABLES	DESCRIPTION
$INV(t)$	set of technologies in t
w_t	average wage level regardless of general skill level
w_t^{RD}	average wage level of workers with highest skill level
e_t	price of energy
int_t	short term interest rate
q_t^{sav}	estimated household saving quota in the economy

PARAMETERS	DESCRIPTION
δ	monthly depreciation rate of capital
ρ	monthly discount factor
α	capital intensity of consumption good production
β	labor intensity of consumption good production
γ	productivity of labor in investment good production
γ^{cons}	efficiency of in the consumption goods sector
γ^{inv}	efficiency of innovation activities in the capital goods sector
q_0^{inv}	initial productivity of investment goods
$\overline{q}_{innov}^{cons}$	average percentage increase of consumption good quality due to one innovation
$\overline{q}_{innov}^{inv}$	average percentage increase of investment good quality due to one innovation
T	planning horizon of firms
w_{min}^R	minimal reservation wage
$prob^{loy}$	probability for a household to go to the same mall as in the previous period
κ	saving propensity of households
ϕ	fraction of employees searching for a job

C.2 Specific for consumption goods producers

VARIABLES	DESCRIPTION
$J_{i,t}$	technology of firm i in t
$B_{i,t}$	the average specific skill level in i
$W_{i,t}$	set of employees
$L_{i,t}$	number of employees
$L_{i,t}^{RD,cons}$	number RD employees
$w_{i,t}$	average wage paid by firm i to production employees
$w_{i,t}^{RD}$	average wage paid by firm i the to R & D employees
$K_{i,j,t}$	capital stock of i and technology j
$I_{i,j,t}$	investment of i in technol0gy j
$A_{i,t}$	average quality of physical capital
$Q_{i,t}$	Output
$q_{i,t}^{cons}$	quality of consumption good
$R_{i,t}$	revenue
$Exp_{i,t}$	total expenditures in period t
$Sav_{i,t}$	savings
$CreditLine_{i,t}$	available financing
$M_{i,t}$	set of malls served
$SL_{i,r,t}$	stock level of firm i in region r
$D_{i,r,t}$	quantity of producer i ordered by mall r in period t
$D_{i,t}$	sum of all quantities ordered by malls served by firm i
$CS_{i,t}$	central stock hold by firm i
$MS_{i,r,t}^{e}$	market share in region r at time t estimated based on past data
$MS_{i,r}^{ma,e}, t$	(potential) market share in region r at time t estimated based on market research
$R_{i,r,t}^{loc,e}$	(potential) revenue in region r estimated based on past data
$R_{i,r,t}^{ma,e}$	(potential) revenue in region r estimated based on market research
$p_{i,r,t}^{c}$	price of consumption good
$\pi_{i,r,t}$	variable profit

PARAMETERS	DESCRIPTION
$\bar{v}$	minimal number of vacancies triggering a wage increase
φ_i	speed of raising wage offers if rationed on the labor market
ϵ	step-size of price adjustment
θ_i	inertia in adjusting prices
κ_i^{inv}	propensity to invest in innovative efforts
ν_i	inertia in adjusting production factors

C.3 Specific for capital goods producers

VARIABLES	DESCRIPTION
$Q_{j,t}^{inv}$	output
$L_{j,t}^{inv}$	number of employees for production
$L_{j,t}^{RD,inv}$	number of employees in R&D
$q_{j,t}^{inv}$	quality of capital good
$p_{j,t}^{inv}$	price of capital good
$w_{j,t}$	average wage paid by firm j to production employees
$w_{j,t}^{RD}$	average wage paid by firm j the to R & D employees
$Sav_{j,t}$	savings
$p_{0_{j,t}}(.)$	base price of capital good
$p_{j,t}^{add}(.)$	quality dependent price component

PARAMETERS	DESCRIPTION
η_j	percentage of value of quality increase passed to customer
κ_j^{inv}	propensity to invest in innovative efforts
$\bar{v}$	minimal number of vacancies triggering a wage increase
φ_j	speed of raising wage offers if rationed on the labor market

C.4 Specific for households

VARIABLES	
b_k^{gen}	general skill level
$b_{k,j,t}$	specific skill level of w for technology j
$w_{k,t}^R$	reservation wage
$B_{k,t}^{cons}$	expenditures for consumption by consumer k
$B_{k,week_t}^{cons}$	consumption budget for $week_t$
$G_{k,week_t}$	set of goods sampled by consumer in week $week_t$
$Ass_{k,t}$	assets
$Inc_{k,t}$	income
σ_t^{inc}	standard deviation of macroeconomic income
$Inc_{k,t}^{Mean}$	individual mean income
$Liq_{k,t}^{avail}$	cash on hand

PARAMETERS	DESCRIPTION
ψ_k	speed of reservation wage adaptation
ζ_k	importance of distance for mall choice
λ_k^{mall}	intensity of choice for mall choice
λ_k^{cons}	intensity of choice for consumption
ς_k^{qual}	weight of quality in utility
ς_k^{rel}	weight of relative quality in utility
Φ	parameter that yields the fraction of mean income which defines the critical value of spending all cash on hand

C.5 Specific for regions

VARIABLES	DESCRIPTION
$v_{r,t}$	number of competing consumption goods producers in region r
$q_{r,t}^{av}$	average quality of goods in mall r
$p_{r,t}^{av}$	average price of goods in mall r
$\hat{y}_{r,t}^{cons}$	potential consumption expenditures in region r

PARAMETERS	DESCRIPTION
P_r	number of households in region r
$Rent_r$	costs of running a sales point in region r

Appendix D

Some stylized facts of the labor market, industry dynamics and innovation activities

In the following we describe stylized facts for selected indicators of labor market performance and industrial evolution. The selection is mostly driven by the type of data which the EURACE model will generate. Accordingly these stylized facts can potentially be used to evaluate the plausibility of simulation results.

D.1 Stylized facts of the labor market

Exposition of the indicators in the labor market is organized along stock-, flow variables, and wages, and within the first two of those two broad categories along supply and demand related indicators capturing aspects of quantity and quality. We focus on European data where possible but also make use of empirical findings for the U.S.

1. Stock data of the labor market

   - *Activity rates* Cross country activity rates for the EU are documented in Commission (2006) chapter 3; the activity rate in year 2005 was 70.2;
   - *Employment rates* Cross country employment rates for the EU are documented in Commission (2006) chapter 3; the employment rate for EU 25 in year 2005 was 63.8;
   - *Skill structure* Evidence on skill structure for EU countries can be found in Commission (2006) Table 10, p. 54; the skill structure measured as educational attainment in percent of the working age population was 32.8, 47.3 and 19.9 for the low, medium and higher skill level, respectively, in year 2005;
   - *Unemployment rates* Cross country unemployment rates for the EU are documented in Commission (2006) chapter 3.3;
   - *Regional labor market disparities* Regional labor market disparities for the EU are documented in Commission (2006) on p. 68; the coefficient of variation for employment rates on NUTS 2 level for EU-25 related to national employment rates was 12.2 in year 2004;

- *Vacancy unemployment ratio, v-u-ratio* U.S. findings mostly for years between 1951-2003: v-u-ratio is downward sloping with a correlation of the percentage deviation of unemployment and vacancies ¿from trend of -0.89; v-u-ration exhibits strong variation, see Shimer (2005); for most of the EU countries v-u-ratios and Beveridge curves are documented in OECD (2001);
- *Correlations with business cycle* U.S. findings mostly for years between 1951-2003: Unemployment is strongly countercyclical; vacancies are strongly procyclical; the correlation between the two is -0.89 at business cycle frequencies; v-u-ratio is procyclical with standard deviation around trend of 0.38 log points, average labor productivity is weakly procyclical with standard deviation about trend of 0.02 log points see Shimer (2005)

2. Wages and productivity

   - *Wage data* Descriptive evidence on Occupational Wages Around the World can be found in Freeman and Oostendorp (2003);
   - *Labor productivity* U.S. findings mostly for years between 1951-2003: productivity is stable never deviating by more than 6 percent from trend, see Shimer (2005); EU evidence on the growth of total factor productivity can be found in Commission (2006) on p. 187
   - *Correlations with business cycle* U.S. findings mostly for years between 1951-2003: Average labor productivity is weakly procyclical with standard deviation about trend of 0.02 log points see Shimer (2005); Romer (1996) on p. 150 report that real wages for the U.S. slightly fall in recessions;

3. Flow data of the labor market

   - *Job finding rate* U.S. findings mostly for years between 1951-2003: monthly job-finding rates for unemployed workers on average at 0.45; standard deviation of job finding rate around trend is 0.12 log points; correlation with v-u-ratio is 0.95, see Shimer (2005); Fallick and Fleischman (2004) report monthly job finding rates of the U.S. for years 1996-2003 of 0.28;
   - *Job separation rate* U.S. findings mostly for years between 1951-2003: monthly job separation rate on average 0.034 which implies average duration of jobs of 2.5 years, see Shimer (2005); see Auer

and Cazes (2000) for evidence on other countries including European ones;

- *Employment-employment-transitions* Fallick and Fleischman (2004) report monthly employment-to-employment transitions of 0.026 for the U.S. for years 1996-2003
- *More transitions* Transition data taking account of the state 'out-of-the labor force' can be found in Fallick and Fleischman (2004); there is also a summary of findings for U.S. data comparing different sources of information and distinguishing job (demand side of labor market) and worker (supply side of labor market) flows in Davis et al. (2006); for example, they postulate that for the U.S. in years 2000-2005, monthly job creation, job desctruction, hires and seperations in percent of employment was 1.5, 1.5, 3.2, and 3.1 respectively (JOLTS data - Job Openings and Labor Turnover Survey)
- *Correlations with business cycle* U.S. findings mostly for years between 1951-2003: unemployment-to-employment and non-participation-to-employment transition rates are stongly procyclical, see Blanchard and Diamond (1990); aggregate job search activity is positively correlated with unemployment; relatively weak counter-cyclicality of seperation rate, see Shimer (2005); Davis et al. (2006) also find that unemployment escape rate is highly procyclical

4. Other data

- *Flow data for Europe* The ILO's Key Indicators for the Labour Market provide some flow data that might be used for drawing a picture for Europe.
- *Firms' training expenditures* The Continuous Vocational Training Survey (CVTS) which is based on firm level data gives information on these issues.

D.2 Stylized facts of industry dynamics and innovation activities

Klette and Kortum (2004) give an excellent synopsis of some of the most important stylized facts in these areas. We will use their descriptions in several places. We present the stylized facts in several groups, where in each group we start with these properties that can be represented in the framework of the EURACE model.

1. Relationship between R & D and other indicators

    - *R & D and Productivity* (Klette and Kortum (2004)): Productivity and R&D across firms are positively related, whereas productivity growth is not strongly related to firm R&D. There is a vast literature verifying a positive and statistically significant relationship between measured productivity and R&D activity at the firm level (see, e.g., Hall (1996); Griliches (1998), chap. 12; 2000, chap. 4). This positive relationship has been consistently verified in a number of studies focusing on cross-sectional differences across firms. The longitudinal (within-firm, across-time) relationship between firm-level differences in R&D and productivity growth, which controls for permanent differences across firms, has turned out to be fragile and typically not statistically significant.
    - *R & D and firm size* (Klette and Kortum (2004)): R&D intensity is independent of firm size. The large literature relating R&D expenditures to firm size is surveyed by Cohen (1995) and Cohen and Klepper (1996). Cohen and Klepper (1996) state that among firms doing R&D, "in most industries it has not been possible to reject the null hypothesis that R&D varies proportionately with size across the entire firm size distribution" (p. 929). However, they also point out, "The likelihood of a firm reporting positive R&D effort rises with firm size and approaches one for firms in the largest size ranges" (p. 928). As pointed out above, Griliches (1990) interprets the appearance of less R&D among small firms as, in part, an artifact of the available data. That is to say, the higher fraction of small firms reporting no formal R&D is offset by small firms doing more informal R&D. Furthermore, smaller firms tend to have a lower absolute level of R&D, and R&D surveys often have a reporting threshold related to the absolute level of R&D. Similarly, the innovative activity being singled out in a firm's accounts as formal R&D is related to the absolute level of R&D.
    - *Persistence of R & D heterogeneity* (Klette and Kortum (2004)): Differences in R&D intensity across firms are highly persistent. Scott (1984) shows that in a large longitudinal sample of U.S. firms, about 50 percent of the variance in business unit R&D intensity is accounted for by firm fixed effects. Klette and Johansen (1998), considering a panel of Norwegian firms in high-tech industries, confirm that differences in R&D intensity are highly persis-

tent over a number of years and that R&D investment is far more persistent than investment in physical capital.

- *R & D and Patents* (Klette and Kortum (2004)): Patents and R&D are positively related both across firms at a point in time and across time for given firms. The relationship between innovation, patents, and R&D has been surveyed by Griliches (1990). He emphasizes that there is quite a strong relationship across firms between R&D and the number of patents received. For larger firms the patents-R&D relationship is close to proportional, whereas many smaller firms exhibit significant patenting while reporting very little R&D. Cohen and Klepper (1996) emphasize this high patent-R&D ratio among the small firms and interpret it as evidence that smaller firms are more innovative. Griliches (1990), however, argues that small firms in available samples are not representative but are typically more innovative than the average small firm. Furthermore, he notes that "small firms are likely to be doing relatively more informal R&D while reporting less of it and hence providing the appearance of more patents per R&D dollar" (Griliches, 1990, p. 1676). There is also a robust patents-R&D relationship in the within-firm dimension: "the evidence is quite strong that when a firm changes its R&D expenditures, parallel changes occur also in its patent numbers" (Griliches (1990), p. 1674). Summarizing the results in Hall et al. (1986) and other studies, Griliches reports that the elasticity of patents with respect to R&D is between 0.3 and 0.6. Revisiting the evidence with new econometric techniques, Blundell et al. (2002) report a preferred estimate of 0.5.

2. Properties of Population Distributions

- *R & D Distribution* (Klette and Kortum (2004)): The distribution of R&D intensity is highly skewed, and a considerable fraction of firms report zero R&D. A number of studies have reported substantial variation in R&D intensities across firms within the same industry (Cohen (1995)). Cohen and Klepper (1992) show that the R&D intensity distribution exhibits a regular pattern across industries. The R&D intensity distributions they present are all unimodal, are positively skewed with a long tail to the right, and have a large number of R&D nonperformers. Klette and Johansen (1998) report the same pattern of a unimodal and skewed R&D intensity distribution based on a sample of Norwegian firms.

- *Size Distribution* (Klette and Kortum (2004)): The size distribution of firms is highly skewed. The skewed size distribution of firms has been recognized for a long time and is discussed in Ijiri and Simon (1977), Schmalensee (1989), and Stanley et al. (1995). As noted by Audretsch (1995), "virtually no other economic phenomenon has persisted as consistently as the skewed asymmetric firm-size distribution. Not only is it almost identical across every manufacturing industry, but it has remained strikingly constant over time (at least since the Second World War) and even across developed industrialized nations" (p. 65).

  De Wit (2005) gives an overview about the shape of firm size distributions in practice. Often a Pareto distribution with a parameter near 1 is found. Only for very small and very large sizes there is a noteworthy deviation from this line (see Axtell (2001)). Ijiri and Simon (1977) and others show that the above-mentioned straight line is in fact somewhat concave. Gibrat (1931) and Stanley et al. (1995) reported that the empirical density function can be described quite well by a lognormal density function. Contrary as for smaller industries either a Pareto nor a lognormal fits Sutton (1997) concludes that probably there is no general density function. Beside the stylized fact of a skewed distribution Dosi et al. (1995) supplements the fact that the distribution appears relative stable over time.

3. Firm Size Effects

   - *Survival Probability* (Klette and Kortum (2004)): Smaller firms have a lower probability of survival, but those that survive tend to grow faster than larger firms. Among larger firms, growth rates are unrelated to past growth or to firm size. This stylized fact has emerged from a number of empirical studies as a refinement of Gibrat's law, which states that firm sizes and growth rates are uncorrelated. Our statement corresponds to the summaries of the literature on Gibrat's law by Sutton (1997), Caves (1998), and Geroski (1998).
   - *Firm Growth Rates* (Klette and Kortum (2004)): The variance of growth rates is higher for smaller firms. This pattern has been recognized in a large number of studies discussed in Sutton (1997) and Caves (1998). It is the focus of recent research by Amaral et al. (1998) and Sutton (2002). Younger firms have a higher probability of exiting, but those that survive tend to grow faster

than older firms. The market share of an entering cohort of firms generally declines as it ages.

4. Effect of Worker Education

   - For the education and training of workers Battu and Sloane (2003) show that there is a strong and significant effect on own earnings arising from the education of co-workers in addition to the effect of own education. An additional year of single colleague's education is worth about 3.2 percent of an additional own year of education. Metcalfe and Sloane (2007) confirm that spillovers from workplace education and training on the pay are substantial and independent from the impact of own education and training. Their investigation of the interaction between own and co-worker years of education shows that it is negative and significant which they interpret as the result of intra workplace competition.

     Dearden et al. (2006) illustrate that a percentage point increase in training was associated with an increase in value added per hour of about 0.6 percent and an increase in wages of only 0.3 percent. There is more evidence that training is likely to increase wages (see Vignoles et al. (2004)), productivity and the chances of commercial survival (Collier and J.Pierson (2005), 2006). Metcalfe and Sloane (2007) demonstrate that the interaction between own and co-workers training has a positive and significant impact on wages, indicating a "complementary" effect or increasing returns to scale of human capital. A greater dispersion of training at the workplace was associated with lower earnings.

5. R & D, Innovation and Industry Dynamics

   - *R & D Dynamics* (Klette and Kortum (2004)): Firm R&D investment follows essentially a geometric random walk. In a study of U.S. manufacturing firms, Hall et al. (1986) conclude by describing "R and D investment [in logs] within a firm as essentially a random walk with an error variance which is small (about 1.5 percent) relative to the total variance of R and D expenditures between firms" (p. 281). Similarly, Klette and Griliches (2000) report zero correlation between changes in log R&D and the level of R&D for Norwegian firms.

   - *Innovation Dynamics* (Klepper (1992), p. 7): During the period of growth in the number of producers, the most recent entrants account for a disproportionate share of product innovations; over time, increasing effort by producers is devoted to process relative to product innovation; over time, the rate of change of firm market shares slows.

- *Population Size* (Klepper (1992)): There is an initial period of fairly steady growth in the number of producers followed by a period in which the number of producers declines sharply.
- *Entry Dynamics* (Klepper (1992)): The time path in the number of entrants up to the peak number of producers does not follow a common pattern for all new products, with the number of entrants sometimes rising up to the peak whereas in other instances it reaches a maximum well before the peak. For all products, though, entry tends to peak at or before the peak in the number of producers and then falls off sharply and stays below exit throughout the shake-out.
- *Product Innovators* (Klepper (1992)): The number of major product innovations tends to reach a peak during the period of growth in the number of producers and then falls over time;

6. Firm Exit and Entry As long as no more elaborated entry process exists in EURACE it might be difficult to reproduce these facts. We still give them for further reference. Most of them are based on Geroski (1995).

   - Entry is common. Large numbers of firms enter most markets in most years, but entry rates (the number of new firms divided by the number of incumbent and entrant firms producing this year) are far higher than market penetration rates (gross sales by entrants divided by total industry sales). For the UK the entry rates ranged from 2.5 percent to 14.5 percent while the entry penetration ranged from 1.45 percent to 6.36.
   - Although there is a very large cross-section variation in entry, differences in entry between industries do not persist for very long. In fact, most of the total variation in entry across industries and over time is "within" industry variation rather than "between" industry variation.
   - Entry and exit rates are highly correlated, and net entry rates and penetration are modest fractions of gross entry rates and penetration. For example during the 1970s in Canada the entry rates averaged 5 percent and exit rates averaged 6.5 percent, leaving a net entry rate -1.5 percent and the correlation between exit and

entry ranged 0.5 and 0.7 (see Baldwin and Gorecki (1991)). Carree and Thurik (1996) mention a correlation between entry and exit of 0.78 for data of teh retail sector in the Netherlands.

- The survival rate of most entrants is low, and even successful entrants may take more than a decade to achieve a size comparable to the average incumbent. Dunne et al. (1989) showed for the US that the market share of each cohort of entrants declined by about 50 percent during the first ten years post-entry and that 79.6 percent excited within ten years.
- De novo entry is more common but less successful than entry by diversification. The typical diversifying firms entered at a scale larger than the incumbent and grew of about 2.5 times the size of the average incumbent over 10 years after entry.
- Entry rates vary over time, coming in waves which often peak early in the life of many markets. Different waves tend to contain different types of entrants. Gort and Klepper (1982) showed that after the introduction of a product many of the markets experienced rapid entry (averaging a net increase of 6 firms per year) over a period of ten years, a levelling off of net entry, and then a contraction phase averaging about 5 firms per year lasting an average about 5 years. Brock (1975) showed at least two generations of entrant appeared in the US computer industry the first were major business machine firms, while the second were new, specialized firms interested in developing and exploiting the new technology.
- Costs of adjustment seem to penalize large scale initial entry and very rapid post-entry penetration rates. Biggadike (1976) illustrates for the US that most of the entrants experienced major losses through the first 4 years of life mostly because of high marketing and R&D expenditures.

Dosi et al. (1995) recapitulate sector specific phenomena. Acs and Audretsch (1990) find that growth rates are significantly different across firm-size classes in about 40 percent of the industries considered in their sample. Also the turbulence differs a lot across sectors. It is relatively lower in industries characterized by high rates of innovation, high advertising, high capital intensity, low concentration and low growth. The probability of survival of new small entrants appears to be lower in capital-intensive industries and in sectors with high rates of innovation and high economies scale. Surviving firms have either a higher initial size or higher growth rates. Bigger initial size implies lower growth, but higher survival probabilities. Surviving firms tend to grow faster in the early periods, but this property fades away in the long-run.

In general Dosi et al. (1995) hint at the fact that firms displaying persistent differences with each other. Firms which enjoy higher profits can be expected to observe higher profits in the future, the profits don't converge to a common rate of return.