

Policy Design in the Presence of
Technological Change –
An Agent-based Approach

Dissertation zur Erlangung des Grades eines
Doktors der Wirtschaftswissenschaften
der Universität Bielefeld

vorgelegt von
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Bielefeld, Mai 2014

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Diese Arbeit wurde auf alterungsbeständigem Papier gemäß ISO 9706 gedruckt.

Acknowledgments

Writing this dissertation would not have been possible without the assistance of many people. I am deeply grateful to my supervisor Prof. Dr. Herbert Dawid for his guidance and encouragement as well as for giving me the opportunity to work in a most inspiring, friendly, and strongly research-oriented environment. He attracted my attention to the promising and interesting field of agent-based computational economics, which is the methodological foundation of this thesis.

My thanks go also to Jun.-Prof. Dr. Sander van der Hoog for being my second advisor and to Jun.-Prof. Dr. Anna Zaharieva for her willingness to be the third advisor in my disputation. I am also indebted to my co-authors Prof. Dr. Michael Neugart, Dr. Simon Gemkow and Dr. Klaus Wersching for the excellent teamwork that led to a several quite interesting research papers.

Furthermore, I have to thank Dr. Bettina Fincke and Gregor Böhl for helpful suggestions during the final stage of my dissertation. And I wish to thank Dr. Dennis Heitmann, Serhat Gezer, Michael Grothe, Michel Yevenunye Keoula, Ph.D, Diana Grieswald, Karin Borchert, and many other colleagues from the Department of Economics and Business Administration for fruitful discussions and great help in all circumstances. Moreover, financial support of the University of Bielefeld, the Department of Economics and Business Administration and the FP-6 project EURACE, financed by the European Commission is gratefully acknowledged.

Last but not least I am truly thankful to my family for setting up all preconditions for this dissertation and especially to Julia for supporting and encouraging me during the course of this dissertation and for her patience when I had to spend parts of our weekends at the desk.

Bielefeld, May 2014

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General Introduction

Economies can be characterized as complex adaptive systems of heterogeneous agents in which the interaction of agents at the micro level forms the macro properties of the economic system, thereby determining the emergence of macro regularities such as economic growth, unemployment, and income distributions. These global regularities in turn feed back into the determination of the interactions at the micro level. The result is a dynamic system of interacting agents and interdependent feedback loops connecting the micro and macro level of the economy (Tesfatsion, 2006). This important aspect of the functioning of economic systems has widely been neglected in contemporary mainstream frameworks based on the paradigm of equilibrium models of representative agents with full rationality.

Unlike its mainstream counterparts, the methodological approach *agent-based computational economics* is able to capture the complexity of dynamical processes that arise through the local interaction of heterogeneous agents. Following Tesfatsion (2006), agent-based computational economics can be defined as the computational study of economic processes modeled as a dynamic system of interacting agents; *agents* refers broadly to an encapsulated collection of data and methods representing an entity residing in a computationally constructed world. Examples of possible agents include individuals (e.g. workers, consumers), social groups (households, firms), and institutions (government, central bank, markets). Thus, agents can range from active information gathering and decision making entities that communicate and interact with other agents to passive institutional agents without any active social functioning. A key aspect of the agent-based approach is its assumption of boundedly rational agents. Bounded rationality means that in decision making agents are limited to information they have and agents do not fully observe all the consequences of their own actions and that of other agents.

Aggregate behavior in agent-based models is generated from the bottom up by explicitly modeling the micro-level interaction of the autonomous agents. Agents behave according to explicit rules describing how different agents take different decisions. This bottom-up approach provides empirically based micro behavior and establishes the emergence of strongly micro-founded macro phenomena through an aggregation of the individual decision making. The complex system in which agents interact evolve over time so that aggregate properties emerge out of repeated interactions of the agents (Fagiolo and Roventini, 2012).

The agent-based approach allows for a highly empirically grounded taxonomic classification of agents by providing a systematic way to incorporate whatever taxonomic classification seems to be useful for the explanatory study of a particular economic phenomenon (LeBaron and Tesfatsion, 2008). Once a taxonomy is specified, the set of agent-specific behavioral rules can be implemented, where the concrete collection of empirically founded rules is subject to their relevance for the particular macroeconomic phenomena under study. Hence, as stressed by LeBaron and Tes-

fatsion (2008), agent-based modeling provides a tremendous flexibility to tailor the breadth and depth of the agents to particular applications at hand. In this context, issues related to keeping the model analytically tractable that constrain the scope of a model play a less prominent role for agent-based modeling.

It is this high degree of flexibility that makes agent-based computational economics to an appropriate tool for the evaluation of economic policy measures. Generally, a policy analysis requires a thorough understanding of the underlying mechanisms driving the effects of the policy under consideration. The choice of candidate explanatory mechanisms and their representation in a model are therefore crucial for the results of the policy analysis, where a consideration of only one or a subset of possible explanatory mechanisms can result in misleading policy recommendations (see Dawid and Neugart, 2011). Such a thorough exploration of different alternative mechanisms is, however, hardly possible in a model framework that has to take account of analytical tractability. Unlike most standard models, agent-based models can incorporate different possible channels in one framework in a flexible manner. The comprehensiveness of agent-based macroeconomic models allows thereby not only to consider different possible mechanisms but also to examine the emergence of simultaneous policy effects on different economic figures. Furthermore, since one of the tenets of agent-based modeling are out-of-equilibrium dynamics of a complex evolving system, this approach enables a policy analysis on different time scales, where policy effects can then be typically distinguished in short-, medium-, and long-term effects.

The requirement of a new complementary methodological approach in macroeconomic theory has become evident during the financial and economic crisis that started in 2008. Standard general equilibrium models were not able to predict the crisis and even after the bubble had broken they were not able to anticipate the severity of the following downturn. Moreover, these models provided little guidance for policymakers on how to get out of the downward spiral (see, e.g., Stiglitz, 2011). It is therefore not surprising that several policymakers have voiced concerns that it is hard for them to base their decisions on existing mainstream models, which might not be able to capture the mechanisms that seem to be mainly responsible for the problems. To quote former ECB President Jean-Claude Trichet:¹

'When the crisis came, the serious limitations of existing economic and financial models immediately became apparent.[...] Macro models failed to predict the crisis and seemed incapable of explaining what was happening to the economy in a convincing manner. As a policy-maker during the crisis, I found the available models of limited help. In fact, I would go further: in the face of the crisis, we felt abandoned by conventional tools.'

Jean-Claude Trichet also sketched properties of economic models that would make them in his opinion more suitable to capture crucial properties of economic systems and make them more appealing to policy makers:

'We need to deal better with heterogeneity across agents and the interaction among those heterogeneous agents. We need to entertain alternative

¹Quoted from the speech 'Reflections on the nature of monetary policy non-standard measures and finance theory' by Jean-Claude Trichet, President of the ECB given as opening address at the ECB Central Banking Conference Frankfurt, 18 November 2010. The text of the full speech is available at <http://www.ecb.int/press/key/date/2010/html/sp101118.en.html> (last accessed on April, 3rd 2014).

motivations for economic choices. [...] Agent-based modeling dispenses with the optimization assumption and allows for more complex interactions between agents. Such approaches are worthy of our attention.’

Agent-based analyses have been carried out for numerous policy areas, where studies related to financial market dynamics, banking regulations, credit linkages and monetary policies have attracted considerable attention. There has also been research aiming at the development of comprehensive macroeconomic models using an agent-based approach. In this respect, a prominent example has been the EURACE project (‘An Agent-based Software Platform for European Policy Design with Heterogeneous Interacting Agents: New Insights from a Bottom-Up Approach to Economic Modeling and Simulation’) which was carried out from 2006 to 2009 within the 6th European Framework Programme by a consortium of economists and computer scientists (see, e.g., Deissenberg et al., 2008). The agenda of this project was to develop a simulation platform containing a software environment, graphical user interfaces and an agent-based macroeconomic model with strong empirical grounding, all together providing a common framework to address issues of different areas of economic policy. Examples of policy analyses that have been carried out with the agent-based model developed during the project (the EURACE model) can be found in, e.g., Dawid et al. (2009, 2012a, 2008).

The EURACE model is the basis for the work presented in this dissertation.² The thesis consists of three independent research papers all covering research questions regarding agent-based macro modeling. Different agent-based models are considered in the papers, where all models share the same roots that reside in the EURACE model. The general aim of the dissertation is to apply the agent-based approach for analyzing concrete structural and fiscal policy measures and to obtain new insights from this analysis that can be utilized in the process of economic policy design. The focus of the policy analysis is thereby on the interplay of these policy measures with the process of technological change. The reason why the role of technological change is emphasized is that technological change is one of the main sources of dynamism in capitalized economies and is therefore a main driver of economic growth (see, e.g., Freeman, 1998). If, however, a policy measure interacts with the process of technological change, then it might have a sustained impact on the economic development in the medium and long term. Therefore, one of the key policy questions is whether these specific economic policies lead to unexpected and non-trivial medium- and long-term implications in the presence of technological change. It is particularly emphasized in how far these implications emerge through interactions and feedback loops of desired policy effects with the diffusion of technologies, the dynamics of productivity and skills, and the labor mobility across firms and between regions. In this context, a further important policy question addressed in the policy analysis is how these policy implications interact with different institutional settings of the economy under study.

As discussed in Dawid (2006), there are some properties of agent-based modeling that make this approach appealing for the analysis of innovation and technological change. One of them is the decentralized decision making of heterogeneous interacting agents, which is also an inherent characteristic of the process of technological change. Dawid (2006) argues, innovation and technological progress can be characterized as a decentralized dynamic search process, in which heterogeneous firms search for new technologies under strong uncertainty, thereby being interlinked with

²The author of this thesis contributed to the EURACE project as a member of the research group at the Bielefeld University led by Herbert Dawid.

other firms through market and non-market interactions. Thus, micro-founded economic models such as agent-based models have the potential to capture the essential effects influencing the phenomenon of technological change.

A policy analysis stressing the role of technological change is clearly focused on the real sphere of the economy and here especially on the production sector. Firms contribute to the process of technological change by either developing new products or processes, or by acquiring improved technologies embodied in new machines. Accordingly, firms as the most relevant actor in the production sector must be modeled with a stronger emphasis than other agents contained in a model of technological change. What is, however, missing in the literature of agent-based modeling is a clear conceptual basis for the choice of firms' decision rules. This methodological shortcoming of the agent-based approach is addressed in the first of the three papers of this thesis (see Chapter 1). This paper reviews different approaches to model firm behavior in agent-based simulation models and proposes the *Management Science Approach*, where well documented heuristics put forward in the managerial literature are used to capture the decision processes of firms. This approach is illustrated within the framework of an extend version of the EURACE model. Then, it is explored how robust the dynamics of this model is with respect to changes of the firms' decision rules within the set of rules proposed by the Management Science Approach. This paper is joint work with Herbert Dawid³ and has been published in the book *Evolution, Organization and Economic Behavior* edited by Guido Bünstorf.

In contrast to the first paper, which considers conceptual issues of agent-based modeling, the two other papers contained in this dissertation provide concrete policy analyses. The second paper, which can be found in Chapter 2, studies the effectiveness of cohesion policies with respect to convergence of regions. The policy analysis relies on simulations carried out with the Eurace@Unibi model, which is a completely revised and in many directions extended and substantially altered follow-up release of the EURACE model (see Dawid et al., 2012b). A two-region setup of the model is used to analyze short-, medium-, and long-term effects of policies improving human capital and fostering the adoption of technologies in lagging regions. In two different scenarios it is examined whether and how the cohesion policies interact with the level of spatial integration of the two local labor markets. With fully integrated labor markets the human capital policy positively affects the economically stronger region but reduces production in the targeted weaker region. Subsidies for high technology investment in the weaker region have a positive local output effect and a negative effect on the neighboring region, thereby fostering convergence. When labor markets are not integrated both policies support convergence. This paper is joint work with Herbert Dawid and Michael Neugart⁴ and has been accepted for publication in the *Journal of Economic Dynamics and Control*.

In the third paper in Chapter 3, the author proposes substantial changes to the Eurace@Unibi model, where especially some of the refinements to the production sector introduced after the completion of the EURACE project have been revised. The result of this major revision is basically a completely new production sector in which especially the investment decision of firms has been modeled in a consistent manner following the *Management Science Approach*. The added value of the revised model is demonstrated by showing that the model generates endogenous business cycles with realistic properties and that the model replicates several stylized facts

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with respect to business cycles, firm size and productivity distributions, and labor market regularities.

This model is then used to carry out a policy analysis regarding the effectiveness of fiscal stabilization policies. The research questions are thereby focused on long-term implications of discretionary stabilization policies. In particular, do fiscal stabilization policies affect the long-term growth of the economy? If so, are the long-term effects growth-enhancing or growth-reducing? These questions have again become relevant to the political and academic debate since governments have been forced to spend considerable funds for economic stimulus packages as a response to the recent economic crisis.

The answers that the economic literature provides are inconclusive. However, the theoretical literature has emphasized the importance of structural issues of the models such as the modeling approach of endogenous technological change or sources of disturbances driving economic fluctuation in the models. In this context, less attention has been paid to the design of the considered fiscal stabilization policies. The importance of the policy design for long-term effects of stabilization policies is demonstrated in the policy analysis of the third paper by comparing a demand-oriented consumption policy and two different investment subvention policies. The comparison shows that all policies are equally successful in smoothing the business cycle but differ in their implications for the medium and long-term growth of the economy. Therefore, not only modeling assumptions and structural issues as stressed by the literature but also the concrete implementation of the policy seem to be important for the long-term effects of stabilization policies and should therefore be taken into account when deciding about stabilization policies.

Besides detailed policy analyses stressing the importance of the interplay between policies and several aspects associated with the process of technological change, the papers in Chapter 2 and 3 also contribute to the literature of agent-based modeling by proposing the use of generalized additive models (GAM) with penalized spline smoothers as statistical tools for the analysis of the simulation outcome (see, e.g., Wood, 2011, for a discussion of GAMs). In particular, it is proposed to use GAMs to identify policy effects (Chapter 2 and 3) and to carry out a systematic sensitivity analysis of the model as well as robustness checks of policy findings, both with respect to a variation of parameters contained in the model (Chapter 3).

All agent-based models used in the simulations for the three papers of the thesis have been implemented in FLAME (Flexible Large-scale Agent-based Modeling Environment)⁵. FLAME is a simulation environment that has been developed by computer scientists within the EURACE project. The data analysis for each of the papers has been based on the statistical software R by using a collection of existing packages and self-written R-scripts.

⁵See <http://www.flame.ac.uk/> for more information (last accessed April, 4th, 2014)

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Chapter 1

Capturing Firm Behavior in Agent-Based Models of Industry Evolution and Macroeconomic Dynamics*

1.1 Introduction

The description of the dynamics emerging from the interaction of different types of economic actors, who independently make decisions and take actions, is a challenging task underlying any analysis of market dynamics, industry evolution or macroeconomic dynamics. This task has been tackled using a number of different approaches. In the area of Evolutionary Economics, the use of agent-based simulation models has traditionally been an important tool and one that continues to attract an increasing amount of research. Starting with the pioneering work of Nelson and Winter (1982) various aspects of industry dynamics have been explored using simulation methods both in rather generic industry frameworks and in specific application areas taking into account characteristic features of the considered industry (see, e.g., surveys in Dawid, 2006; Safarzynska and van den Bergh, 2010). Recently substantial effort has also been invested in the development of agent-based closed macroeconomic models that capture the interplay of different markets and sectors in the economy while at the same time providing an explicit representation of behavior of different types of potentially heterogeneous actors and the institutions governing their (local) interaction patterns (e.g. Dawid et al., 2009; Delli Gatti et al., 2005; Dosi et al., 2010; Silverberg and Verspagen, 1993). In the tradition of Evolutionary Economics, this kind of work is based on the assertion that economic systems generically are not in equilibrium and aims to explore of properties that emerge from certain assumptions about micro-behavior and micro-structure.

In contrast to dynamic equilibrium models, where it is assumed that the behavior of all actors is determined by maximization of the own (inter-temporal) objective function using correct expectations about the behavior of the other actors, agent-based simulation models need to provide explicit constructive rules that describe how different agents take different decisions. The need to provide such rules is not

*This chapter has been published as H. Dawid and P. Harting (2012): "Capturing Firm Behavior in Agent-Based Models of Industry Evolution and Macroeconomic Dynamics," in *Evolution, Organization and Economic Behavior*, edited by G. Büntorf, Edgar-Elgar.

only based on the basic conviction underlying these models, that in most economic settings actual behavior of decision makers is far away from inter-temporally optimal behavior under rational expectations, but also on the fact that in most models incorporating heterogeneity among agents and explicit interaction protocols (e.g. market rules) the characterization of dynamic equilibria is outside the scope of analytical and numerical analysis. Given that need to specify explicit rules for all decisions taken by all actors in an agent-based model the determination and motivation of the implemented rules becomes a major modeling issue. The 'Wilderness of bounded rationality' (Sims, 1980) is a serious concern since a large number of different approaches to model boundedly rational behavior and its adaptation have been put forward in the literature and at this point there is little indication for the emergence of a widely accepted consensus that provides empirically or theoretically well founded concepts for tackling this issue (see, e.g., Hommes, 2009). Providing such concepts however seems important for several reasons. First and foremost, it would add to the credibility of agent-based models and the normative implications derived from such models in the areas of firm strategy, market design or economic policy. Second, the comparison between results derived in different models capturing different economic settings is facilitated if these models share a common approach to modeling certain (standard) decision processes, such as the consumption choice of households or pricing and investment of firms. Third, if the structure of the considered rules for a given type of decision can be restricted, for example to a parametrized family of rules, the test for robustness of simulation results becomes much easier, since it involves only the consideration of parameter variations rather than of structural changes in the decision rule.

The most suitable approach to provide empirical or theoretical foundations for certain types of rules depends strongly on the type of agent that is to be modeled. Describing the decision rule of an individual choosing a consumption good is very different from capturing the rule determining the interest rate decisions of a central bank. In fact, the interest rate decision of a central bank is one of the few types of decisions where there indeed seems to be some consensus about the structure of the corresponding decision rule within the agent-based models that include a central bank. Since central banks have an interest in making their decision processes transparent and predictable, there is something similar to publicly documented decision rules (like the Taylor rule) which can be easily implemented in an agent-based model. If we consider decisions taken by individuals rather than an institution like a central bank such documentation of the rules or processes leading to a decision is missing. An obvious candidate to obtain empirically founded insights into the decision processes of individuals in different economic frameworks is the consideration of experimental evidence. The fast growing literature in experimental and behavioral economics provides a rich basis to develop empirically grounded representations of individual decisions in agent based models. There is quite a bit of work linking experimental with agent-based work (see, e.g., the survey in Duffy, 2006) and recently attempts have been made to design individual decision and learning rules as well as expectation rules in agent-based models in a way such that they closely resemble experimental evidence (e.g. Arifovic and Ledyard, 2008; Hommes, 2009)).

The focus of this article is on the representation of firm decisions in agent-based models. Most decisions of firms that are typically considered in agent-based models are taken according to well structured processes and are only to a small extent at the discretion of individual decision makers. Hence, evidence from laboratory experi-

ments might be of limited use when developing models of firms' decision rules¹. The fact that firms in many domains indeed follow well established routines or heuristics has been highlighted in the literature on evolutionary theory (Nelson, 2005; Nelson and Winter, 1982) but is also evident from considering the Management literature. For many decision problems relevant for a firm standard decision heuristics have been developed in the corresponding literature in Management Science and Operations Research. They are presented in the main textbooks for Business Studies and have been at least partly implemented in decision support software available to companies. Hence, for many decision problems of firms there exist well documented algorithms that determine or at least strongly influence the way the corresponding decisions are taken in a large percentage of firms. Paying attention to such decision algorithms and trying to implement them in an agent-based framework should provide additional empirical grounding for the models and also lead to a stronger standardization of the representation of firms' decisions.

The purpose of this article is to highlight how such an approach, which we call the 'Management Science Approach' can be used in different economic settings to derive descriptive and in particular normative insights into firm behavior and policy design. Prior to the treatment of the Management Science Approach in the framework of a macroeconomic model (Section 3) we will give a brief discussion and categorization of the approaches to the modeling of firm decision that are present in the literature (Section 2). A concluding discussion is given in Section 4.

1.2 Approaches to modeling firm decisions in ACE: a brief survey

To put the different approaches for modeling firm decision processes that have been put forward in the agent-based literature into perspective it might be useful to realize that the role of firms and their decision processes depends crucially on the research agenda underlying the study under consideration. At least three different branches of the literature that have attracted considerable attention can be distinguished in this respect. First, papers that deal with the effects of policy interventions or changes in market characteristics on market outcomes, industry dynamics or growth (e.g. Dawid et al., 2009, 2008; Dosi et al., 2010; Li et al., 2010; Malerba et al., 2001; Nelson and Winter, 1982; Winter, 1984). Here the focus is not on the firms behavior, but on the effects of certain changes in the economic environment *given* the decision rules (and maybe their adjustment dynamics) of the firms. Obviously, different types of decision rules for firms might, in principle, generate quite different effects of these change in the economic environment. Therefore, although the exact form of the decision rules used might not be of major importance, the validity of the derived market design or policy conclusions is strongly affected by the empirical foundation of the considered rules and the robustness of the qualitative conclusions with respect to changes of the rules within an (empirically) reasonable range. The largest part of the ACE literature where firm behavior plays some role falls into this category. Second, there is some literature exploring the characteristics of firm strategies that evolve in particular market frameworks (e.g. Dawid and Reimann,

¹It should be noted that we do not deal here with issues of the organization of the firm including the organization of certain decision processes. Experimental, evolutionary and agent-based research has been very active in this area (see, e.g., Chang and Harrington, 2006), but at this point in Agent-based Computational Economics (ACE) models of industry-dynamics and macro-dynamics the inner structure of firms has not been explicitly represented.

2004, 2010; Dosi et al., 1999; Midgley et al., 1997). Here the focus is on the firm strategy and, depending on the way decision rules and their updating is modeled, the structure of the decision rule might be quite flexible without requiring strong assumptions about its characteristics (see e.g. the brief discussion of Dosi et al., 1999, below). However, to a certain degree this just transfers the problem of the empirical or theoretical foundation to the level of the rule adjustment process. The properties of the evolved strategies in general depend on the type of adjustment process considered and any conclusions drawn about properties of (long run) strategies therefore rest on the validity of the underlying adjustment process or the robustness of these properties with respect to changes of this process. Finally, a third stream of literature has treated the question under which kind of assumptions about market environment and learning behavior ex-ante uncoordinated firms can in the long run coordinate their behavior and in how far this coordinated behavior resembles Nash or Walras equilibria (e.g. Arifovic, 1994; Arifovic and Maschek, 2008; Dawid and Kopel, 1998; Price, 1997; Vriend, 2000). It turns out that even in a given standard market environment, like a Cournot oligopoly, convergence of behavior and also the equilibrium selection in case of convergence depends crucially on the way firm strategies are represented (Dawid and Kopel, 1998) or updated (Arifovic and Maschek, 2008; Vriend, 2000).

Within these different branches of literature quite a wide range of approaches for representation, design and updating of firms' behavioral rules have been used. In order to give a somehow systematic overview we have tried to categorize these approaches, without however claiming that this listing is exhaustive or the categorization is in any way generic.

- **Fixed Rules with Heuristic Basis:** Maybe the most common way firms' decision behavior is represented in ACE models is the use of relatively simple fixed decision rules that are motivated by (sometimes anecdotal) empirical arguments or plausibility considerations. Examples include the original Nelson and Winter model of Schumpeterian competition where innovation and imitation expenses as well as investments in physical capital are determined by simple closed form functions that stay constant over time and the output decision is made using the assumption that capacities are always fully exploited (see Nelson and Winter, 1982). Frequently used simple decision rules with empirical foundations are fixed mark-up pricing rules and R&D-rules assuming constant R&D intensities of firms (see, e.g., Dosi et al., 2003).
- **Adaptation of Actions:** In this approach the behavior of a firm is updated over time due to (typically evolutionary) learning, where the object that is adapted over time is the action itself (e.g. price, quantity) rather than some rule determining the action (e.g. Arifovic, 1994; Vriend, 2000). Since the economic environment in models of this type is often assumed to be static, the fact that firms' *actions* are updated over time due to processes like imitation or reinforcement could be interpreted as a short-cut for assuming that the decision rules determining the actions are adjusted in such a way and then applied to more or less static input data. Another underlying assumption could be that firms do not follow any structured decision rules to come up with this decision, but evaluate their different action choices in each period entirely based on past performance of different choices by the firm itself and its competitors. How reasonable such an interpretation is seems to depend strongly on the kind of decision that is considered. In particular for standard operational decisions,

like production decisions, pricing, investment this interpretation however seems to be rather far-fetched.

- **Adaptation of Rules:** Decisions of firms are taken according to rules that change over time. Either the structure of the rules is fixed and rule parameters are adjusted over time (e.g. Winter, 1984; Yildizoglu, 2002) or the representation of the rule is so flexible that its whole structure (including the set of variables that are taken into account) can evolve over time. A nice example in this respect is Dosi et al. (1999), where the rules determining the pricing decisions of firms in an oligopoly are represented as genetic programming trees and are updated by standard genetic programming operators. Potential input data for the rules consists of past observations of all prices, aggregate demand quantity, own costs and market share. It is shown that the rules that emerge in the long run lead to trajectories where the price a firm charges is moving almost in parallel to the costs. This means that although a large variety of pricing rule structures would be available to the firm, in the long run a pricing rule very close to a mark-up rule with constant mark-up is adopted by the firms. Other examples of the emergence of firms' decision rules in large rule spaces are Marks (1992), Midgley et al. (1997).

1.3 A Management Science Approach to Model Firm's Decision Making

Considering the brief literature survey in the previous section several observations can be made. First, as discussed earlier, only a small fraction of work in this area refers to actual firms' decision processes when motivating the employed modeling approach. Second, typically decision rules are represented by closed form functions of certain input variables, but there is very little consideration of actual processes or algorithms that are used to come up with certain decisions, although in principle agent-based models would allow the capture of such decision structures. Third, in the agent-based literature firms typically do not engage in any kind of explicit optimization of an objective function. The insight that determining equilibrium behavior in such models is typically infeasible and that firms act boundedly rational would not necessarily imply such an absence of optimization. In related literature (see, e.g. Day, 1999) models have been suggested where decision makers build simplified models of their economic environment and then choose their action in a way to maximize their objective within their simplified internal model. Also many heuristic decision rules for managerial decisions result from optimization in relatively simple models that abstract from many complex aspects of the firm's decision problem.

The Management Science Approach, which we will illustrate in this section, aims at implementing relatively simple decision rules that match standard procedures of real world firms as described in the corresponding management literature. There is a rich literature on (heuristic) managerial decision rules in many areas of management science. This includes pricing (see, e.g., Nagle and Hogan, 2006), production planning (see, e.g., Silver et al., 1998) or market selection (see, e.g., Kotler and Keller, 2009; Wind and Mahajan, 1981). Although, it certainly cannot be assumed that all firms in an economy rely on such standard managerial heuristics, capturing the main features of these heuristics when modeling the firm adds a strong empirical micro foundation to the agent-based model.

To be more specific about the Management Science Approach let us consider the

modeling of firm decisions in a large agent-based macroeconomic model that was initially developed in the European project EURACE and extended afterward (see Dawid et al., 2009, 2010; Deissenberg et al., 2008) for treatments of previous versions of the model). We only sketch some main features of the model here that allow the firm decisions we will focus on to be put into perspective. A more extensive description of the model is given in the Appendix. The model describes an economy containing labor, consumption goods, capital goods, financial and credit markets in a regional context. Each agent, these are firms, households and banks, is located in one of the regions. The spatial extensions of the markets differ. The capital goods market is global, meaning that firms in all regions buy from the same global capital goods producer and therefore have access to the same technology. On the consumption goods market demand is determined locally in the sense that all consumers buy at regional markets, denoted as 'malls', that are located in their region, but supply is global because every firm might sell its products in all regional markets of the economy. Labor markets are characterized by spatial frictions determined by commuting costs that arise if workers accept jobs outside their own region. The basic time unit in the model is one day, where many decisions, like production choice or hiring of firms, are taken monthly.

In what follows we will concentrate on decisions of consumption goods producers in this model. These firms use a vintage capital stock and labor to produce the consumption goods on a monthly basis. The consumption goods are then distributed to the different regions this producer serves. For simplicity it is assumed that all producers offer their products in all regions. Each producer keeps a stock of its products at each of the regional malls and offers the goods at a posted price that is updated once a month at the point in time when the stock is replenished.

All sales of consumption goods take place at the malls. Each household determines once a month the budget which it will spend for consumption based on its income and its assets carried over from the previous period. Once a week the household then visits the (regional) mall to purchase consumption goods. When visiting the mall each consumer collects information about the range of goods provided and about the prices and inventories of the different goods. 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 modeled 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 rely on a model of that kind and assume that a consumer's decision which goods to buy is random, where purchasing probabilities are based on the values the household attaches to the different choices he is aware of. In particular, these values are influenced by the prices at which the different producers offer their goods. If possible, each household spends his entire planned weekly consumption budget at the mall. If the stock of a certain producer at the mall is empty when the household visits the mall, then this product is excluded from the consumer's consideration, which means that the producer is losing potential sales. The introduction of the regional malls is supposed to capture in a simple way the interaction on regionally separated consumption goods markets with search frictions, storage of goods and potential rationing on both market sides.

Overall, a consumption goods producer has to make a large number of decisions affecting different markets, but focusing on the mall transactions this boils down to two major decisions. First, which quantities should be delivered to each mall in a given period and, based on this, how much should be produced in a given month.

Second, which price should be posted at the malls in a given period. We will discuss several aspects of these two decisions in the remainder of this section.

Let us first consider the monthly quantity decision of a consumption goods producer. On a given day of the month (which might differ between different producers) the firm receives messages from all the malls it serves reporting the current stock levels. Based on this information the firm calculates its sales at each mall every month. Due to the fluctuations in consumption budgets of households and the stochastic aspects of the product choice decisions, sales at the malls fluctuate in a non-deterministic way. Furthermore, it is costly for a producer to keep the stock at a mall so low that it is fully sold during the month, because households arriving after the stock has been depleted will buy from competitors rather than put off their consumption, and therefore potential sales are lost. This means that the producer in our agent-based economy faces for each of the malls a production planning problem with stochastic demand and out-of-stock costs, where the delivery intervals are given and fixed. Such problems have been extensively treated in the Operations Management literature as 'Newsvendor problems'. Procedures, how to treat such problems are presented in most standard textbooks in this area. Although these procedures are based on optimal solutions to certain optimization problems, they are heuristics in the sense that the underlying optimization problem is a simplified representation of the actual problem abstracting from aspects like competition or intertemporal effects. Furthermore, they are relatively easy to implement and therefore widely applicable. A standard approach for firms to deal with Newsvendor problems of this type is the use of a policy where the firm replenishes its stock in each period up to a given level Y . In order to determine Y the firm estimates the demand distribution for the following period and then chooses Y in a way that the stock-out-probability under the estimated demand distribution matches a certain target value. This target value depends on inventory and stock-out costs and also crucially on the risk attitude of the firm.

Although this decision heuristic cannot be represented in a single closed form expression, it is straight forward to implement it in an agent-based model. In the EURACE model firms follow this heuristic, where the stock-out probability used by the firm is considered as an important strategy parameter. Below we will consider effects of changes in this parameter on the dynamics of produced output on the aggregate level. The actual implementation of the rule in the model then proceeds as follows. Let vector $\{\hat{D}_{i,r,t-\tau}, \dots, \hat{D}_{i,r,t-1}\}$ denote the estimated demands² for the good of firm i reported by mall r during the last τ periods. Furthermore, $SL_{i,r,t}$ is the firm's current mall stock on the day in period t when the stock is checked. Following the procedure described above the firm chooses its desired replenishment quantity for region r according to the following rule:

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

where $Y_{i,r,t}$ is chosen such that the firm expects to be able to satisfy the market demand with some probability $1 - \chi$. Again following standard procedures described in the managerial literature demand distribution in the following period is estimated

²This quantity is identical to actual sales in all periods where the stock was not emptied during the month. In periods where the product of the firm was sold out at this mall the estimated demand is larger than the actual sales.

using a linear regression based on previous demands. Put formally,

$$Y_{i,r,t} = \hat{a}_{i,r,t} + \tau \cdot \hat{b}_{i,r,t} + \bar{q}_{1-\chi} \cdot \sqrt{\hat{\sigma}_{i,r,t}^2},$$

where $\bar{q}_{1-\chi}$ is the $1 - \chi$ quantile of the standard normal distribution and the regression coefficients $\hat{a}_{i,r,t}$ and $\hat{b}_{i,r,t}$ as well as the variance $\hat{\sigma}_{i,r,t}^2$ are estimated using standard linear regression methods.

The sum of the orders received by all malls becomes

$$\tilde{D}_{i,t} = \sum_{r=1}^R \tilde{D}_{i,r,t}.$$

In principle this should be the production quantity of the firm, but to capture rigidities in production plan adjustments the consumption good producer shows some inertia in adapting the actual production quantity to the quantity requested by the malls. In particular, we have

$$\tilde{Q}_{i,t} = \xi \tilde{D}_{i,t} + (1 - \xi) \frac{1}{T} \sum_{k=t-T}^{t-1} \tilde{Q}_{i,k},$$

where $\tilde{Q}_{i,t}$ is the planned production quantity of firm i in period t . As discussed in more detail in the Appendix, the realized production volume $Q_{i,t}$ can deviate from the planned output $\tilde{Q}_{i,t}$ due to rationing on the factor markets. The quantities actually delivered to the malls, $D_{i,r,t}$, are adjusted proportionally to the intended quantities $\tilde{D}_{i,r,t}$ so that

$$D_{i,r,t} = \frac{\tilde{D}_{i,r,t}}{\tilde{D}_{i,t}} Q_{i,t}.$$

Production times of consumption goods are not explicitly taken into account and the produced quantities are delivered on the same day as production. The local stock levels at the malls are updated accordingly.

This representation of the quantity decision of firms is not only based on a clear empirical basis, but also leads within the EURACE model to realistic properties of time series on the macro level (see Dawid et al., 2009, 2008). Several parameters govern the procedure, in particular, the number of past observations used to estimate the demand distribution (τ) and, more importantly, the stock-out probability parameter χ . Although empirical evidence allows to values of this parameter to be restricted to some plausible range, an important consideration is in how far conclusions drawn from the model are robust with respect to changes of the parameter within this range. The main purpose of the EURACE model is to allow the analysis of effects of different policy measures, like innovation policies or labor market policies, on the dynamics of the economy as whole and of different sectors. Hence, the effects of changes of the stock-out parameter χ on aggregate variables of the economy are of main interest. In figure 1.1 we show the effect of changes of χ on per capita output of the economy. The different time series depict averages over 10 runs carried out for the corresponding stock-out probabilities. The figure clearly shows that, although the aggressiveness of firms with respect to their production planing somehow influences the total output in the economy, qualitative changes in the dynamics appear only for an extreme stock-out probability of 80%.

Let us now turn to the pricing decision of the firm. As discussed earlier, a very popular approach to capture price determination in agent-based models is the use

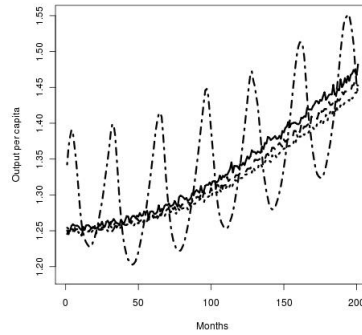


Figure 1.1: Dynamics of per capita output averaged over 10 runs for different values of the stock-out probability: $\chi = 0.01$ (solid line), $\chi = 0.1$ (dashed line), $\chi = 0.2$ (dotted line), $\chi = 0.8$ (dashed-dotted line).

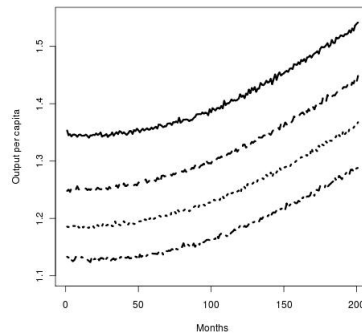


Figure 1.2: Dynamics of per capita output averaged over 10 runs for different values of the mark-up: 5% (solid line), 10% (dashed line), 15% (dotted line), 20% (dashed-dotted line).

of mark-up pricing, where typically the mark-up is assumed to be constant over time. Although there is extensive empirical evidence for, wide-spread use of mark-up pricing in the real world, it is much less clear what determines the size of the mark-up chosen by a firm. The size of the mark-up chosen by the firms does not only have effects on the performance of the individual firms, but, as can be seen in figure 1.2, also strongly influences the level of the overall output in the economy. The figure demonstrates that an increase of the mark-up by all consumption good producers from 5% to 20% reduces the per-capita output by about 20%. This strong effect is quite surprising because the closed EURACE model takes into account that firm profits that might be generated by large mark-ups is to a large extent channeled back to households, and thus to consumption, through firms' dividend payments.

These observations suggest that a careful analysis of empirically meaningful mark-up values and of the way the mark-up level is set can be an important factor in providing confidence in the conclusions drawn from simulation results. As is also well known from microeconomic theory, the two crucial factors determining the price a firm should charge are (marginal) costs and the elasticity of the demand for the product of this firm with respect to its price. In particular the elasticity of the firm's individual demand is however typically unknown to a firm operating in a dynamic complex environment and therefore can only be estimated. In the management liter-

ature heuristic procedures are proposed that would in the ideal world of oligopolies with full information about demand and cost lead to standard elasticity-based pricing, but are also applicable in more messy environments where the actual demand structure is unknown to the firm. We adopt here a simple heuristic of this kind that can be summarized as follows if it is applied to the EURACE economy (see, e.g., Nagle and Hogan, 2006, pp. 136):

For each considered price change do the following:

- i) Determine the effects of changes in sales on production costs.
- ii) Evaluate buyers' price sensitivity and determine a sales distribution after the price change.
- iii) Calculate profit implications for various probable sales changes.
- iv) Accept or reject the proposed price change based on these considerations.

Step [iv)] of this procedure of course depends strongly on the objective of the firm. In our implementation of this procedure we assume that the firm maximizes expected profits and therefore compares the expected profit implications of the different price changes it considers. The main challenge of this procedure lies in step [ii)], where the firm has to determine the expected change in its sales for different potential price changes. To address this challenge we again rely on a procedure put forward in the relevant literature, "namely simulated purchase surveys" (see, e.g., Nagle and Hogan, 2006, pp. 300). Such surveys are performed by presenting consumers a sample of products of the firm under consideration and its competitors together with prices and asking the consumers which product they would choose. Based on the results of these surveys the sensitivity of buyers with respect to price changes can be estimated.

To implement this procedure in our model we assume that each firm carries out market research and updates its prices once a year. From the household population it draws a sample where the sample size n_S has to be sufficiently large in order to obtain significant results. Therefore, the firm contacts randomly chosen households by sending an interview request. Contacted households decide whether they are willing to attend an interview based on a random process. If firms are not able to recruit the planned number of interviews n_S on their activation day, they repeat the recruiting on the following days until the desired number is reached. Attending households receive a questionnaire containing a set of prices and goods where both the good of the firm and those of the competitors are included. The households are asked whether they would buy firm's good at one of these prices or if they would decide on a different good offered at its original price. The simulated purchasing decision is based on the same logit model that households use for their real purchasing decision. Based on these answers the firm determines the expected change in sales coming with each of the considered price changes and calculates the corresponding profit implications taking into account the cost effects of the change in sales. Among all considered price changes the one with the highest expected profit is then chosen.

In figure 1.3 we show the dynamics of the resulting mark-ups of firms for a single run. The bold line depicts the population mean, the dashed lines indicate the band of plus/minus one standard deviation. The population mean is quite stable over time fluctuating slightly in a range between 10% and 15%. The heterogeneity within the population is however substantial and also persistent, as can be seen from the standard deviation band. So it can be concluded that the standard setting

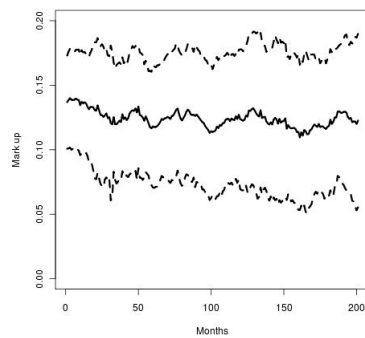


Figure 1.3: Dynamics of the mark-up charged by firms in a single simulation run. The bold line gives the population mean the dashed line the mean plus/minus one standard deviation.

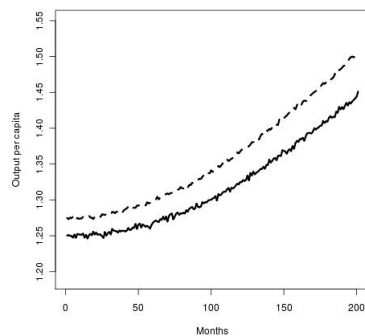


Figure 1.4: Dynamics of per capita output averaged over 10 runs for synchronized (dashed line) and asynchronous (solid line) firm decisions.

with a fixed mark-up of 10% for all firms is close to what would emerge from this endogenous mark-up rule but misses the persistent heterogeneity of mark-ups in the firm population. To what extent the consideration of such persistent heterogeneity in firm behavior would affect qualitative properties of the aggregate dynamics or of policy effects depends on the particular research issue and cannot be discussed here.

Having discussed an empirically founded way to model the quantity and pricing decisions in terms of parametrized families to decision heuristics and having examined some robustness properties of the results with respect to changes in the parameters of the heuristic, we now briefly discuss another important issue of the description of the firm behavior in agent-based models, namely the synchronization, or lack thereof, of the points in time where different firms in the economy make their decisions. In the majority of agent-based models, as in almost all models examining market or industry dynamics, the time structure consisting of discrete periods without any further fragmentation implies complete synchronization of the decisions of firms. It is well known that such synchronization is prone to producing overshooting phenomena and for many firm decisions such strong synchronization cannot be observed in reality. The EURACE model allows one to study how the assumption that the points in time where firms act are fully synchronized influences the dynamics of the model. As briefly discussed above, in the EURACE model the basic time unit is a day, but many decisions are taken once a week, once a month or

once a quarter. The quantity and pricing decisions of firms are taken once a month, which means that each firm has one fixed day of the month where it applies the procedures described above to determine these values. In the standard setting it is assumed that each firm chooses its 'day to act' randomly and hence the decisions of the different firms are distributed over time, but full synchronization can be achieved by assigning identical days to act to all firms. Figure 1.4 shows that synchronization of firm decisions does indeed have a non-negligible effect on the emerging dynamics. Rather surprisingly, the effect of synchronization is positive, leading to an increase in per-capita output of almost five percent. Actually, the effect of the synchronization of the firms is larger than the effect of a decrease in the stock-out probability from $\chi = 0.2$ to $\chi = 0.01$ by all firms. This highlights that the usual assumption of synchronization of firms' action in ACE models should be treated with caution and if possible robustness considerations should be made not only with respect to parameter variations but if possible also with respect to the schedule of events in a period. The actual mechanisms and causal chains leading to the positive effect of synchronization could be identified examining the interrelated dynamics of different micro-variables, see Dawid et al. (2009, 2010) for examples of extensive examinations of the economic mechanisms on the micro level that give rise to certain macro level effects of different economic policy measures. Although certainly interesting, we abstain here from presenting such a detailed analysis of the effect of synchronization in our model. Rather we want to stress the general point that the assumption of synchronized actions often does have substantial implications.

1.4 Conclusions

In this paper we have argued that in agent-based models of industry and macro dynamics relatively little attention has been paid to the way decision-making processes of firms are modeled. While in recent literature the effort to provide empirical and experimental foundations for the description of decisions by *individuals* in agent-based models has increased, a clear conceptual basis for the choice of firms' decision rules in such models is often missing. A potentially fruitful approach seems to be the Management Science Approach where decision heuristics that are well documented in the relevant managerial literature are implemented in the agent-based model in order to capture the decision processes of the firms. Here this approach has been illustrated in the framework of an agent-based macro model where the focus of the analysis lies on understanding the dynamics on the aggregate level and the effects of policy interventions. It should however be pointed out that the Management Science Approach has also been applied with success in quite different contexts and with a quite different focus. In Dawid and Reimann (2004) a normative analysis from the perspective of the firm was carried out using this approach. In particular they used parametrized families of decision rules taken from the managerial literature to examine how the optimal firm strategy with respect to product range expansion and market selection depends on the properties of the industry environment and the strategies adopted by the competitors. This study shows that the Management Science Approach also has potential as a tool to carry out strategic analysis from a firm perspective using agent-based modeling.

Obviously, more work is needed to increase the appeal of the approach. Standard decision heuristics for different types of firm decisions relevant in ACE models will have to be collected and empirical evidence about which published decision heuristics are indeed applied by a majority of the firms should be provided. Even if such

empirical studies showed that the percentage of firms following standard managerial heuristics is relatively small such research contributing to the development of an empirically founded systematic approach for the modeling of firm decisions in ACE models would be most welcome.

1.A Appendix: Detailed description of the (extended version of the) EURACE model

Although some parts of the model have been described in detail in the body of the paper we have repeated them here for easier readability of the entire model description.

1.A.1 Overall Structure

The model describes an economy containing labor, consumption goods, capital goods, financial and credit markets in a regional context. Each agent (firms, households and banks) is located in one of the regions.

Capital goods are provided with infinite supply at exogenously given prices. The quality of the capital goods improves over time where technological change is driven by a stochastic (innovation) process. Firms in the consumption goods sector use capital goods combined with labor input to produce consumption goods. The labor market is populated with workers that have a finite number of general skill levels and acquire specific skills on the job which they need to fully exploit the technological advantages of the capital goods employed in the production process. Consumption goods are sold at malls. Malls are treated as local market platforms where firms store and offer their products and consumers come to buy goods at posted prices.

The spatial extensions of the markets differ. The capital goods market is global meaning that firms in all regions buy from the same global capital good producer and therefore have access to the same technology. On the consumption goods market demand is determined locally in the sense that all consumers buy at the local mall located in their region, but supply is global because every firm might sell its products in all regional markets of the economy. Labor markets are characterized by spatial frictions determined by commuting costs that arise if workers accept jobs outside their own region. The basic time unit in the model is one day, where many decisions, like production choice or hiring of firms, are taken monthly and others, like consumption decisions of households are taken weekly.

Table 1.1 summarizes the setup of the model by showing the values of the most important model parameters.

1.A.2 Consumption goods producer

1.A.2.1 Quantity choice and factor demand

For a detailed description of the quantity choice, the reader is referred to Section 1.3.

Consumption goods producers need physical capital and labor to produce the consumption goods. A firm i has a capital stock $K_{i,t}$ that is composed of different vintages of the production technology $\mathbb{V} = \{V\}_1^{Vmax}$,

$$K_{i,t} = \sum_{V=1}^{Vmax} K_{i,t}^V. \quad (1.1)$$

The accumulation of physical capital by a consumption goods producer follows

$$K_{i,t+1} = \sum_{V=1}^{Vmax} (1 - \delta) K_{i,t}^V + \sum_{V=1}^{Vmax} I_{i,t}^V \quad (1.2)$$

where δ is the depreciation rate and $I_{i,t}^V \geq 0$ is the gross investment in vintage V .

Every worker w has a level of general skills $b_w^{gen} \in \{1, \dots, b_{max}^{gen}\}$ and a level of specific skills $b_{w,t}$. The specific skills of worker w indicate how efficiently the corresponding technology is exploited by the individual worker. Building up those specific skills depends on collecting experience by using the technology in the production process. The specific skills are updated once in each production cycle of one month. Further, we assume that updating takes place at the end of the cycle.

A crucial assumption is the positive relationship between the general skills b_w^{gen} of a worker and his ability to utilize his experiences. Taking the relevance of the general skill level into account the specific skills of a worker w for technology j is assumed to evolve according to

$$b_{w,t+1} = b_{w,t} + \chi(b_w^{gen}) \cdot \max[A_{i,t} - b_{w,t}, 0], \quad (1.3)$$

where we denote with $A_{i,t}$ the average quality of the capital stock over all vintages. The function χ is increasing in the general skill level of the worker.

The production technology in the consumption goods sector is represented by a Leontief type production function with complementarities between the qualities of the different vintages of the capital goods and the specific skill level of employees for using these types of technologies. Vintages are deployed for production in descending order by using the best vintage first. For each vintage the effective productivity is determined by the minimum of its productivity and the average level of relevant specific skills of the workers. Accordingly, output for a consumption goods producer is given by

$$Q_{i,t} = \sum_{V=1}^{Vmax} \min \left[K_{i,t}^V, \max \left[0, L_{i,t} - \sum_{k=V+1}^{Vmax} K_{i,t}^k \right] \right] \cdot \min [A^V, B_{i,t}], \quad (1.4)$$

where A^V is the productivity of vintage V and $B_{i,t}$ denotes the average specific skill level in firms.

Let $\tilde{Q}_{i,t}$ be the planned production quantity of firm i in t and $\hat{Q}_{i,t}$ the feasible output that can be produced with the current capital stock. This potential output is computed according to

$$\hat{Q}_{i,t} = \sum_{V=1}^{Vmax} (1 - \delta) K_{i,t}^V \cdot \min [A^V, B_{i,t}]. \quad (1.5)$$

Two cases have to be considered for the factor demand determination:

1. If $\hat{Q}_{i,t} \geq \tilde{Q}_{i,t}$: In that case the desired output can be produced with the current capital stock and no additional investments are necessary. We have $I_{i,t} = 0$ and the labor input is computed by taking the labor productivity of the last month into account:

$$\tilde{L}_{i,t} = \tilde{Q}_{i,t} \cdot \frac{L_{i,t-1}}{Q_{i,t-1}}. \quad (1.6)$$

2. If $\hat{Q}_{i,t} < \tilde{Q}_{i,t}$: Here we have positive investments $I_{i,t} > 0$; the amount depends on the outcome of the vintage choice (see next section). If V is the selected vintage, the investment volume is

$$I_{i,t} = \frac{\tilde{Q}_{i,t} - \hat{Q}_{i,t}}{\min[A^V, B_{i,t}]} \quad (1.7)$$

and the labor demand

$$\tilde{L}_{i,t} = K_{i,t-1}(1 - \delta) + I_{i,t}. \quad (1.8)$$

1.A.2.2 Vintage choice

The consumption goods firm can choose from a set of vintages $\mathbb{V} = \{V\}_1^{V^{max}}$ which differ regarding their productivity A^V . The decision in which vintage to invest depends on a comparison of the effective productivities and the corresponding prices. For this consideration the complementarity between specific skills and technology, $\min[A^V, B_{i,t}]$, plays an important role: due to the inertia of the specific skill adaptation, the advantage of a better vintage with $A^V > B_{i,t}$ cannot be fully taken into account immediately, but the productivity gap is closed over time. To account for this updating process the firm computes a discounted sum of estimated effective productivities over a fixed time horizon S . Therefore the specific skill evolution has to be estimated for each time step within this period $[t, t + S]$ by using equation 1.3 with as parameters the firm's mean general skill level $B_{i,t}^{gen}$ and mean specific skill level $B_{i,t}$. Formally, we have

$$\check{A}_{i,t}^{Eff}(V) = \sum_{s=0}^S \left(\frac{1}{1 - \rho} \right)^s \min[A^V, \tilde{B}_{i,t+s}(A^V)], \quad (1.9)$$

where ρ is the discount rate and the estimated adaption follows

$$\tilde{B}_{i,t+s} = \tilde{B}_{i,t+s-1} + \chi(B_{i,t}^{gen}) \cdot \max[A^V - \tilde{B}_{i,t+s-1}, 0]. \quad (1.10)$$

A logit model is applied for the vintage choice. The decision is random where the probabilities depend on the ratios of effective productivity and prices $\frac{\check{A}_{i,t}^{Eff}(V)}{p_t^V}$. The higher the ratio is for a certain vintage the higher is the probability to buy it. Formally, we have for vintage V :

$$Prob_{i,V,t} = \frac{\exp(\gamma \log(\frac{\check{A}_{i,t}^{Eff}(V)}{p_t^V}))}{\sum_{v \in \mathbb{V}} \exp(\gamma \log(\frac{\check{A}_{i,t}^{Eff}(v)}{p_t^v}))}. \quad (1.11)$$

1.A.2.3 Financial management

If a firm does not have sufficient internal financial resources to cover all expenses related to production, it has the opportunity to raise external financing on the credit market. Banks accept credit requests by taking into account individual risks of the applicant and risks of their loan portfolio according to some stylized Basel II standards. If the credit request is refused or not fully accepted the firm has to reduce its planned production quantity as long as the planned expenditures can be financed.

The wage bill of the full month as well as capital investments are paid on the day when the firm starts production.

The monthly realized profit of a consumption goods producer is the difference between sales revenues achieved in the malls and production costs (i.e. labor costs and discounted capital costs) in the period just ended. In case of positive profits, the firm pays dividends to its shareholders and the remaining funds or losses are entered on a payment account $Acc_{i,t}$. We assume that all households hold equal shares in all consumption goods producers, consequently the dividends are equally distributed to the households.

Besides the expenditures for production, i.e. labor costs and investments, the firm has also financial obligations such as taxes on profits, installment and interest payments. If the firm is not able to pay these financial commitments it goes out of business. It also goes bankrupt if the firm's equity becomes negative. In case of bankruptcy it fires all its employees, writes off a fraction of its debt and stays idle for a certain period before it becomes active again.

1.A.2.4 Pricing

The managerial pricing rule corresponds to standard mark-up pricing. The firms set the price according to

$$p_{i,t} = c_{i,t} \cdot (1 + \mu), \quad (1.12)$$

where $\bar{c}_{i,t}$ denotes unit costs in production of firm i in the current period and μ the exogenously given mark-up. 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.

1.A.3 Investment goods producer

The capital goods sector is represented by a single capital goods producing firm. The capital good is heterogeneous and consists of different vintages varying in their technological productivities. The vintages of the capital goods are offered with infinite supply.

The quality of the best practice technology increases over time due to a stochastic process. Every period the quality is increased with probability $\gamma^{inv} \in (0, 1)$ where with probability $(1 - \gamma^{inv})$ there is no change in quality. In case of an increase, the quality of the best practice technology changes by a fixed percentage Δq^{inv} ; this newly developed technology is added as a new vintage to the range of offered vintages without replacing an old one.

The investment goods producer is modeled as a passive agent meaning that although producing goods the firm does not deploy any input factors for production and consequently does not bear any production costs. Revenues accruing to the capital goods producer are channeled back into the economy by distributing them in equal shares among all households in order to close the model.

The pricing of capital goods is based on a combination of two pricing methods. Even if the capital good firm produces at no cost, capital goods pricing is connected to the labor cost trend in the economy. In our model the development of wages is mainly driven by the progress of workers' productivity B^{Eco} . Thus, a cost based price component, which is assumed to be equal for all vintages, evolves over time according to

$$p_t^{Cost} = \frac{B_t^{Eco} - B_{t-1}^{Eco}}{B_{t-1}^{Eco}} \cdot p_{t-1}^{Cost}. \quad (1.13)$$

The second price component is value-based pricing. The value that a vintage has for the buyer can be derived from its effective productivity in the production process of a consumption goods firm. For its determination the investment goods firm replicates the way consumption good producers compute the discounted effective productivity gains. It computes these values for an average firm, i.e. a firm that has economy-wide averages for the general skills B_{Eco}^{gen} and specific skills B_t^{Eco} . For the average firm the discounted sum for vintage V over a time horizon S is denoted by

$$\check{A}_t^{Eff}(V) = \sum_{s=0}^S \left(\frac{1}{1-\rho} \right)^s \min[A^V, \tilde{B}_{t+s}^{Eco}(A^V, b_{Eco}^{gen})]. \quad (1.14)$$

The relative difference of V to a benchmark vintage is used to compute the value based price component $p_{V,t}^{Value}$, where the benchmark is the best practice $Vmax$ of the previous period $t-1$:

$$p_{V,t}^{Value} = p_{t-1}^{Vmax} \frac{\check{A}_t^{Eff}(V)}{\check{A}_{t-1}^{Eff}(Vmax)}. \quad (1.15)$$

Finally, the price of the vintage is a linear combination of p_t^{Cost} and $p_{V,t}^{Value}$ with weight θ ,

$$p_t^V = \theta \cdot p_t^{Cost} + (1-\theta)p_{V,t}^{Value}. \quad (1.16)$$

1.A.4 Households' consumption

Once a month households receive their income. Depending on the available cash, that is the current income from factor markets (i.e. labor income and dividends distributed by capital and consumption goods producers) plus assets carried over from the previous period, the household sets the budget which it will spend for consumption and consequently determines the remaining part which is saved. On a weekly basis, sampling prices at the (regional) mall the consumer decides which goods to buy.

1.A.4.1 The savings decision

At the beginning of period t , a consumer k decides on the budget $B_{k,t}^{cons}$ that he plans to spend. In period t the agent receives an income $I_{k,t}$, and has a total wealth $W_{k,t}$, consisting of money holdings and asset wealth in firm shares.

The consumer sets his consumption according to the following consumption rule

$$B_{k,t}^{cons} = I_{k,t}^{Mean} + \kappa \cdot (W_{k,t} - \Phi \cdot I_{k,t}^{Mean}), \quad (1.17)$$

where $I_{k,t}^{Mean}$ is the mean individual income of an agent over the last T periods and the parameter Φ is the target wealth/income ratio. The intuition is that as long as household wealth matches the target level, the consumption budget $B_{k,t}^{cons}$ corresponds to household's mean income $I_{k,t}^{Mean}$. If it does not match, the budget has to deviate from the mean income so that the actual wealth can converge to the target level. Parameter κ indicates how sensitive the consumption reacts to deviations of the actual wealth/income ration to the target level.

Each consumer goes shopping once a week, but different households on different days. 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 weekly consumption budget $B_{k,week_t}^{cons}$ for each week in period t .

1.A.4.2 Selection of consumption goods

The consumer collects information about the range of goods provided. He receives information about prices and inventories. In the Marketing literature it is standard to describe individual consumption decisions using logit models. We assume that a consumer's decision which good to buy is random, where purchasing probabilities are based on the 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. Since in our setup there are no quality differences between consumer goods and we also do not explicitly take account of horizontal product differentiation, choice probabilities depend solely on prices. The value of consumption good $i \in G_{k,week_t}$ is then simply given by

$$v_k(p_{i,t}) = -\ln(p_{i,t}). \quad (1.18)$$

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

$$Prob_{k,i,t} = \frac{\text{Exp}[\lambda_k^{cons} v_k(p_{i,t})]}{\sum_{i' \in G_{k,week_t}} \text{Exp}[\lambda_k^{cons} v_k(p_{i',t})]}. \quad (1.19)$$

Thus, consumers prefer cheaper products and the intensity of competition in the market is parameterized by λ_k^{cons} . Once the consumer has selected a good he spends his entire budget $B_{k,week_t}^{cons}$ 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 as 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.

1.A.5 Labor market

1.A.5.1 Labor demand

Labor demand is determined in the consumption goods market. If the firms plan to extend the production they post vacancies and corresponding wage offers. The wage offers $w_{i,t,g}^O$ for each general skill group g stay unchanged as long as the firm can fill its vacancies, otherwise the firm updates the wage offer by a parameterized fraction. In case of downsizing the incumbent workforce, the firm dismisses workers with lowest general skill levels first.

1.A.5.2 Labor supply

Labor supply is generated by the unemployed. An unemployed k only takes the posted wage offer into consideration and compares it with his reservation wage $w_{k,t}^R$. 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 person by his adjusted past wage. An unemployed worker will thus 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.

1.A.5.3 Matching algorithm

According to the procedures described in the previous sections, consumption good producers review once a month whether to post vacancies for production workers. Job seekers check for vacancies. The matching between vacancies and job seekers works in the following way:

- Step 1: The firms post vacancies including wage offers.
- Step 2: Every job seeker extracts from the list of vacancies those postings to which he fits in terms of his reservation wage. Job seekers rank the suitable vacancies. He sends an exogenous determined number of applications to randomly chosen firms.
- Step 3: If the number of applicants is smaller or equal to the number of vacancies the firms send job offers to every applicant. If the number of applicants is higher than the number of vacancies firms send job offers to as many applicants as they have vacancies to fill. Applicants with higher general skill levels b_w^{gen} are more likely to receive a job offer.
- Step 4: Each worker ranks the incoming job offers according to the wages net of commuting costs ($comm > 0$) that may arise if he were to accept a job in the region where he does not live. 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 are adjusted for filled jobs and the labor force is adjusted for new employees.
- Step 6: If the number of untitled vacancies exceeds some threshold $\bar{v} > 0$ the firm raises the base wage offer which is paid per unit of specific skills by a fraction φ_i such that $w_{i,t+1}^b = (1 + \varphi_i)w_{i,t}^O$. If an unemployed job seeker did not find a job he reduces his reservation wage by a fraction ψ_k , that is ($w_{k,t+1}^R = (1 - \psi_k)w_{k,t}^R$). There exists a lower bound to the reservation wage w_{min}^R 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. $w_{k,t}^R = w_{i,t}$. Go to step 1.

This cycle is aborted after two iterations even if not all firms may have satisfied their demand for labor. As indicated above this might lead to rationing of firms on the labor market and therefore to deviations of actual output quantities from the planned quantities. In such a case the quantities delivered by the consumption good producer to the malls it serves is reduced proportionally. This results in lower stock levels and therefore increases the expected planned production quantities in the following period.

Table 1.1: Parameter settings

Description	Parameter	Value
Number of households		1600
Number of firms		80
Number of regions	R	1
Depreciation rate of capital (monthly)	δ	0.01
Monthly discount factor	ρ	0.95
Production smoothing	ξ	0.5
Stock-out probability (default value)	χ	0.2
Mark-up factor (default value)	$\frac{1}{ \epsilon_i^e -1}$	0.1
Wage update	φ_i	0.01
Reservation wage update	ψ_k	0.02
Intensity of choice by consumers	λ_k^{cons}	7

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Chapter 2

Economic convergence: policy implications from a heterogeneous agent model*

2.1 Introduction

There is a persistent gap in terms of economic performance and growth between different European regions. Despite large efforts to integrate European economies the problem of real convergence in the European Union (EU) area is to a large degree still unsolved and the effectiveness of the cohesion policy measures is contested (see, e.g., Aiello and Pupo, 2012; Boldrin and Canova, 2001; Cappelen et al., 2003).

EU policies to facilitate convergence of per capita income and productivity refer to two broad areas. First, there is the funding of regional policies. The European Fund for Regional Development (ERDF), the European Social Fund (ESF), the Cohesion Fund (CF), and the Instrument for Pre-Accession Assistance (IPA) are the major pillars to spur cohesion. Second, European integration has to a large degree, also been associated with the reduction of barriers for a free flow of goods, labor, and capital.

This free flow of goods and production factors, however, makes it hard to predict the spatial distribution of the policy effects and to specifically target economic policy measures on the lagging regions. It is *ex ante* not clear how a policy affects the economic performance of neighboring regions, and how the neighboring regions' economic performance feeds back on the region at which the policy is targeted. Due to such feedbacks the overall effect might well be negative such that a policy intended to accelerate the convergence actually leading to divergence.

In our paper we analyze exactly these questions by considering short-, medium- and long-term effects of policy measures, which aim at fostering convergence, on output and real convergence in a two-region setup of an agent-based macroeconomic model (the Eurace@Unibi model). We define two policies that can be implemented in the less developed region. The first policy is a human capital policy that leads to an upgrade of the general skill level in the population. The second policy provides subsidies to those firms that invest in the most recent technological vintages. These subsidies give firms incentives to modernize their capital stock which can close the

*This chapter has been published as H. Dawid, P. Harting and M. Neugart (2014): "Economic convergence: policy implications from a heterogeneous agent model," *Journal of Economic Dynamics and Control*, Volume 44.

technological gap to the superior region.

The choice of these policies for our experiments is strongly motivated by the regional policies funded by the European Union.¹ The ERDF aims at strengthening economic and social cohesion in the EU by correcting imbalances between its regions. In short and among other things, the ERDF finances direct aid to investments in companies (in particular small and medium sized enterprises) in order to create sustainable jobs. Large parts of this fund are spent to support investments in physical capital, mostly through non-repayable grants, but also other tools, such as soft loans. The ERDF also supports the build-up of infrastructures notably linked to research and innovation, telecommunications, environment, energy and transport. The ESF is set up to improve employment and job opportunities in the European Union. This fund supports actions in the member states in the areas of adapting workers and enterprises, lifelong learning schemes, designing and spreading innovative working organizations. It also targets at strengthening human capital by reforming education systems and setting up a network of teaching establishments. This short description shows that under the roof of these funds, we find mostly policies targeted at helping to build up human capital and/or technology improvements.

The available budget for the ERDF and ESF is sizeable. For the period from 2007 to 2013, 277 bn Euros are allocated which makes about 28.5% of the total EU budgeted. As all the cohesion policy programs are matching funds with co-financing by the member countries, total available funding is almost 560 bn Euros which is about one quarter of the Italian and more than one half of the Spanish yearly gross domestic product.

Although there is a vivid debate about the past success of EU cohesion policy, which is based on a variety of econometric techniques (see Becker et al., 2010, for a recent contribution and a brief survey of the relevant literature), the model-supported basis for a prediction of the effect of such measures, which target either the quality of human capital or technology upgrading in a spatial framework with labor market frictions, is weak.² Considering the well established complementarity between workers' skills and the level of technology employed by firms (see our brief discussion in the next section) it is clear, that each of these policies, if successful, should affect the dynamics of both human and physical capital. The effective use and the adoption of different vintages of technology in a region are influenced not only by policies directly subsidizing physical investments, but also by the skill distribution in that region, which is in turn influenced both by local human capital policies and by the mobility of workers. Hence, although these cohesion policies all aim at the improvement of the productivity in the target region, they rely on quite different mechanisms and might therefore be differently affected by varying degrees of spatial labor market frictions. For this reason, a systematic comparison of the effectiveness of policies targeting human capital endowment and diffusion of technologies into

¹See [http : //ec.europa.eu/regional_policy/the_funds/index_en.cfm](http://ec.europa.eu/regional_policy/the_funds/index_en.cfm), accessed on August 9th, 2012.

²A rare model-based contribution related to the issues raised here is Arcalean et al. (2012), where the authors study in the framework of a two region, two sector overlapping generations model the effects of the allocation of structural funds between public education and infrastructure. However, the paper differs in several respects from our main focus. First, infrastructure provides a public good increasing productivity of all firms, whereas the technology policy in this paper provides incentives for individual firms to acquire capital goods of high quality thereby improving productivity of some selected firms (those who invest). Second, a major aspect of our analysis, namely the complementarity between the dynamics of skills of workers and technology choices of firms, is not present in Arcalean et al. (2012). Also, spatial labor market frictions play no role in their analysis.

weaker regions as well as the interplay of these policies with the policies fostering labor mobility between the regions needs further investigation. More specifically we seek to answer the following policy related questions:

1. How does each of the considered cohesion policies affect output growth in both regions and convergence?
2. How are the cohesion policy effects influenced by labor mobility?

Our aim is to address these questions under consideration of the complementarity of the dynamics of skills and quality of production technology on the firm level, where this complementarity is due to learning by doing of workers and endogenous technology choice by firms. Dealing with this complementarity requires a model that captures technology choices of individual firms, where these choices are affected by firm specific characteristics like the availability of appropriate skills in the own workforce, as well as the evolution of the distribution of (specific skills) in the workforce and skill specific labor flows across regions.

We opt for a closed agent-based model with two regions as the most appropriate tool to gain insights into the emergent dynamics on the labor and goods markets.³ Heterogeneous firms and households interact on labor and consumption goods markets. Productivity of firms is determined by the specific skills of its workers (which are updated due to learning by doing) as well as the quality of its vintage structured capital stock. New vintages become available over time from the capital goods sector and are integrated into the active capital stock based on investment and vintage choice decisions of firms. Decision making of firms and households is modeled in a rule-based manner, where the decision rules implemented in the model have strong empirical foundations and resemble heuristics or rules of thumb that have been put forward in the specific literature streams that deal with the different decision problems arising for the agents in the model. This framework allows us to use a strongly micro-founded model for the analysis of short, medium and long run policy effects arising from heterogeneous and interacting firms and workers in a spatial context. We set up the model in a way that one region is initially endowed with a capital stock whose technological level is close to the frontier, while the other region's capital shows a considerable gap. The human capital differs in that the labor force in the first region is better educated and, by working with the most recent technology, has acquired higher specific skills than workers in the other region. Regions may be within a country or could be interpreted as two different countries subject to a fixed exchange rate regime.

In order to examine the effectiveness of the policies targeted at the human capital and technologies, and to identify the importance of regional labor market frictions, on output and convergence, we run and compare two different experimental setups. The two setups, within which the human capital and technology policies are analyzed, differ with respect to the level of integration of the two local labor markets. In the first setup the labor markets are fully integrated such that there are small frictions and all workers have almost unhindered access to both local labor markets. In the other setup the labor markets are completely separated and workers can only work in their home region. These are two extremes where the former may be seen as the political aim of an integrated European labor market. Actual labor mobility across regions varies quite substantially within Europe (see, e.g., European Commission, 2006). Across larger distances and language barriers labor flows are relatively

³Introductions to agent-based modeling can be found, e.g., in Tesfatsion and Judd (2006), LeBaron and Tesfatsion (2008) or Fagiolo and Roventini (2012).

small, although it increased after the recent EU enlargement.⁴ Commuting across regions is a more relevant source of labor flows with the percentage of commuters ranging from 2% to 20% for different EU countries. The largest part of the commuting takes place between regions within the same country (European Commission, 2006).

Our analysis is based on a systematic statistical analysis of batches of simulation runs under the different policies in the two considered labor market scenarios. As a methodological innovation to the literature on agent-based policy models we use penalized spline estimates to capture the evolution of policy impacts over time.

The main results of our analysis are that the human capital policy is only effective in terms of fostering cohesion if labor markets are separated. If labor markets are integrated, output actually falls in the lagging region at which the policy is targeted. Technology policies speed up convergence for integrated and separated labor markets and their effect is substantially stronger if they are specified such that they incentivize firms to purchase latest vintages. The mechanisms responsible for the strong influence of spatial labor market frictions on the policy effects are identified and discussed. Thereby this paper contributes to a better qualitative understanding of the reasons why cohesion policy measures might have no effect or even effects that run counter the intention of the policy maker. The mechanisms we identify rely on the interplay of labor flows of low and high skilled workers with the technology choices of firms in a region and the shift of demand due to the competitiveness of firms in different regions, and do not seem to have been considered in the existing literature. Also, the consideration of policy effects on different time scales is an innovative contribution relative to previous model based policy analyses.

These insights have clear policy implications. Our results suggest that distinct EU policies aiming to speed up convergence are potentially offsetting each other. The HC-policy and the Tech-policy are more effective with respect to achieving convergence if labor markets are not integrated. This insight from our model squares well with findings from the empirical literature on the effect of EU funding. As we outline in the following section, there seems to be evidence that EU policies may foster convergence between countries while they rather fail to spur convergence between regions. Interpreting the differences between countries and regions as workers being more mobile between regions and less mobile between countries, this part of the empirical evidence on the effects of EU policies is what our model predicts for HC-policies. Thus policies, that target the improvement of labor mobility between regions may render policies targeting the cohesion of regions ineffective.

In the following section we relate our contribution to the existing literature. Section 2.3 lays out the model. Section 2.4 introduces the policy experiments and discusses the results. The last Section 2.5 concludes.

2.2 Related Literature

Our contribution on evaluating the effects of EU policies on convergence is mainly related to three streams of literature: work on the effects of cohesion policies, work on the effect of technology policies and a skilled labor force on growth, and work on agent-based macroeconomic modeling. We briefly discuss our contribution relative to these three streams.

⁴In 2010, 2.8% of working-age European citizens lived in another EU member state compared to 2.0% in 2004 (European Commission, 2011).

A large literature has studied convergence between countries or between regions, mainly relying on the concept of ' β -convergence' (see, e.g., Islam, 2003, for a review). Previous empirical work on, particularly, the effectiveness of European regional policies with respect to regional convergence is mixed. Studies taking a national perspective, such as Beugelsdijk and Eijffinger (2005) find positive effects of the Structural Funds Program on GDP growth, or at least conditionally positive effects (Ederveen et al., 2006) meaning that growth rates rise for countries with good institutions. For studies using disaggregated regional data, the findings with respect to the growth effects are inconclusive. One of the earliest attempts to evaluate the role of the Structural Funds Programme can be found in Boldrin and Canova (2001). They analyzed NUTS 2 data for 221 regions for the years 1980 to 1996, finding that disparities between regions were neither growing nor decreasing, and that EU policies have little relationship with fostering growth. Contrarily, also using sub-national data, Cappelen et al. (2003) for example, find positive growth effects. Ramajo et al. (2008) provide evidence for spatial convergence clubs in Europe, and faster conditional convergence in relative income of cohesion-fund countries, i.e. Ireland, Greece, Portugal, and Spain. Finally, Becker et al. (2010) detect positive growth effects for so-called Objective 1 transfers within the structural program but no effects on regional employment. Reasons for the differing findings may be that the data employed refers to various levels of disaggregation, and that some studies look into the overall effect of the EU funding while others evaluated more specific programs.

Recently, based on a model of technology adoption as laid out in Comin and Hobijn (2010), Comin and Hobijn (2011) provided evidence that U.S. aid given within the Marshall plan accelerated the speed of adoption of new technologies. Recurring on a sample of 10 technologies for 39 countries for the postwar period, they find that countries which benefited from these policies reduced on average the adoption lag for new technologies by 4 years. We differ from this work by modeling technology adoption as a process for which the availability of a skilled workforce within a particular firm is crucial. In that sense, our modeling of firms' technology choices also distinguishes this contribution from the work based on the concept of directed technological change (see, e.g., Acemoglu, 1998; Acemoglu and Zilibotti, 2001). There, it is assumed that the intensity of R&D leading to high quality capital goods is influenced by the (local) skill distribution of workers. Our focus is on the effects of the local skill distribution on the *technology choice* of consumption good producers and, therefore, on the speed of diffusion of new technologies in the economy. Such an approach is backed by empirical evidence, based on firm level data, that the intensity of a firm's innovative activities is (positively) influenced by the skill level of its work force (see, e.g., Piva and Vivarelli, 2009).

A simple macroeconomic model, where the technology choice of firms is influenced by the local availability of skills, is developed and analyzed in Caselli and Coleman (2006). They, however, do not consider the role of workers' endowments of skills on the firm level for the technology choices of firms and their work does not have a policy focus.

Similarly to our policy experiments Mateos-Planas (2001) investigates school effectiveness and distortions to the costs of technology adoption on per-capita output, educational attainment, and age of technologies. Technology specific learning and education either improves the ability of agents to learn new technologies or provides a productivity advantage. In contrast, we model the interplay of general and specific skills of workers within a firm, and incentives of firms to invest into new technologies. Workers improve their specific skills on-the-job (see, e.g., Argote and Epple,

1990) faster if they have higher general skills. Also, contrary to our contribution, the analysis by Mateos-Planas (2001) lacks the spatial dimension.

Combining empirical work with a theoretical arguments based on an endogenous growth model, Aghion et al. (2009) show that in regions, where productivity is far from the frontier, educational investments in (research oriented) universities have negative effects on local growth rates, due to the outwards-migration of high-skilled workers. Although this empirical observation is in accordance with our findings the main focus of our underlying model is quite distinct from that in Aghion et al. (2009). Contrary to our focus on the interplay of the dynamics of firm's technology choice, workers' skill adjustment and inter-regional competition, they mainly study the allocation of workers between imitative and innovative activities in a region, assuming that the elasticity of skilled labor is higher in innovation than in imitative activities. Furthermore, in their paper predictions of the effects of policies regard long run growth rates in one region, whereas we consider as well short and medium run effects. In that sense our analysis should be seen as complementary to that in Aghion et al. (2009).

Finally, we contribute to the literature on agent-based macroeconomic modeling. These agent-based models contrast to the previously laid out approaches. Generally speaking, the underlying idea is to study emergent phenomena at aggregated levels arising through the interaction of heterogeneous agents. Unlike in their counterparts, in agent-based models choices do not follow from the assumption that representative agents inter-temporally optimize some objective function under rational expectations. Rather the behavior of agents is modeled using rules that have well-established (empirical) foundations. Micro-behavior may differ between agents and they do not fully oversee all the consequences of their own actions and that of other agents. Heterogeneity is allowed to a large degree and there is an explicit aggregation of individual behavior. In that sense, these model have a strong micro-foundation and aggregation is not simply achieved by the assumption of a representative agent. Moreover, aggregation of individual decisions may end up in situations where markets do not clear. Thus economic frictions may result from the fact that economic agents are not fully coordinated in their (market-) actions.

In the last ten years a number of closed macroeconomic models using an agent-based approach have been developed (see, e.g., Ashraf et al., 2011; Dawid et al., 2012a; Delli Gatti et al., 2010; Dosi et al., 2013, 2010; Gintis, 2007; Raberto et al., 2012; Riccetti et al., 2013; Wolf et al., 2012). Several of these agent-based macroeconomic models have shown the importance of the approach for economic policy design. For example, the effect of labor market integration policies on the convergence of regions are analyzed by Dawid et al. (2012a). Dosi et al. (2010) look into the (long run) effects of policies aiming at the strengthening of demand and of policies facilitating the speed of technological change as well the interaction of these policies. Monetary policies are addressed in Ashraf et al. (2013) or Arifovic et al. (2012), whereas regulatory issues relating to credit and financial markets are analyzed by Delli Gatti et al. (2010), Ashraf et al. (2011), Dosi et al. (2013) or Riccetti et al. (2013) within agent-based macroeconomic models. We differ from the existing agent-based macroeconomic models as our set-up jointly features a spatial dimension and technology adoption by firms which is complementary to an evolving stock of specific skills within a firm.

2.3 The Model

2.3.1 Overall Structure

The Eurace@Unibi model describes an economy containing labor, an investment and a consumption goods sector, and a financial and a credit market in a regional context. Capital good firms provide investment goods of different vintages and productivities. Consumption good firms combine this capital and labor of varying degrees of general and specific skills to produce a consumption good that households purchase. Households' saved income goes into the credit and financial markets through which it is channeled to firms financing the production of goods.

Due to space constraints we describe only the main aspects of the model, which are crucial for the understanding of the results discussed below. This subsection provides a global overview of the model, the following subsections elaborate crucial parts in more detail. A detailed description of the entire model is provided in Dawid et al. (2012b).

Capital goods of different quality are provided by capital goods producers with infinite supply. The technological frontier (i.e. the quality of the best currently available capital good) improves over time, where technological change is driven by a stochastic (innovation) process. Firms in the consumption goods sector use capital goods combined with labor input to produce consumption goods. The labor market is populated with workers that have a finite number of general skill levels and acquire specific skills on the job, which they need to fully exploit the technological advantages of the capital employed in the production process. Every time when consumption goods producers invest in new capital goods they decide which quality of capital goods to select, thereby determining the speed by which new technologies spread in the economy. Consumption goods are sold at local market platforms (called malls), where firms store and offer their products and consumers come to buy goods at posted prices. Labor market interaction is described by a simple multi-round search-and-matching procedure where firms post vacancies, searching workers apply, firms make offers and workers accept/reject. Wages of workers are determined, on the one hand, by the expectation at the time of hiring the employer has about the level of specific skills of the worker, and, on the other hand, by a base wage variable, which is influenced by the (past) tightness of the labor market and determines the overall level of wages paid by a particular employer. Banks collect deposits from households and firms and give credits to firms. The interest that firms have to pay on the amount of their loan depends on the financial situation of the firm, and the amount of the loan might be restricted by the bank's liquidity and risk exposure. There is a financial market where shares of single asset are traded, namely an index bond containing all firms in the economy. The allocation of dividends to households is, therefore, determined by the wealth of households in terms of their stock of index bonds. The dividend paid by each share at a certain point in time is given by the sum of the dividends currently paid by all firms. The central bank provides standing facilities for the banks at a given base rate, pays interest on banks' overnight deposits and might provide fiat money to the government.

Firms that are not able to pay the financial commitments declare illiquidity. Furthermore, if at the end of the production cycle the firm has negative net worth insolvency bankruptcy is declared. In both cases it goes out of business, stops all productive activities and all employees lose their jobs. The firm writes off a fraction of its debt with all banks with which it has a loan and stays idle for a certain period before it becomes active again.

The spatial extensions of the markets differ. The capital goods market is global and, therefore, consumption good firms have access to the same technologies. On the consumption goods market demand is determined locally in the sense that all consumers buy at the local mall located in their region. Supply on this market is global because every firm might sell its products in all regional markets of the economy. Labor markets are characterized by spatial frictions determined by commuting costs that arise if workers accept jobs outside their own region. Finally, it is assumed that firms have access to all banks in the economy, i.e. credit markets operate globally. Our setup reflects the consequences of the Single Market Programme of the EU which aims at integrating the goods, services, and financial markets (European Commission, 2012), and the implementation of a transition phase to remove labor mobility barriers with the onset of the Eastern enlargement.

The choice of the decision rules in the Eurace@Unibi model is based on a systematic attempt to incorporate rules that resemble empirically observable behavior documented in the relevant literature. Concerning households, this means that, for example, empirically identified saving rules are used and purchasing choices are described using models from the Marketing literature with strong empirical support. With respect to firm behavior we follow the 'Management Science Approach', which aims at implementing relatively simple decision rules that match standard procedures of real world firms as described in the corresponding management literature. A more extensive discussion of the Management Science approach can be found in Dawid and Harting (2012).⁵

In several parts of the Eurace@Unibi model choices of decision makers are described by logit models. These models are well suited to capture decisions where individuals try to maximize some objective function which depends on some variables common to all decision makers and are explicitly represented in the model, as well as on aspects that are idiosyncratic to each decision maker and captured in the model by a stochastic term.

Agent actions can be time-driven or event-based, where the former can follow either subjective or objective time schedules. Furthermore, the economic activities take place on a hierarchy of time-scales: yearly, monthly, weekly and daily activities all take place following calendar-time or subjective agent-time. Agents are activated asynchronously according to their subjective time schedules that is anchored on an individual activation day. These activation days are uniformly randomly distributed among the agents at the start of the simulation, but may change endogenously (e.g., when a household gets re-employed, its subjective month gets synchronized with the activation day of its employer due to wage payments). This modeling approach is supposed to capture the decentralized and typically asynchronous nature of decision making processes and activities of economic agents.

2.3.2 Agents, Markets, and Decisions

2.3.2.1 Output Decision and Production

Consumption goods producers need physical capital and labor for production. A firm i has a capital stock $K_{i,t}$ that is composed of different vintages v with $v = 1, \dots, V_t$, where V_t denotes the number of available vintages a time t . The accumulation of physical capital by a consumption goods producer follows

$$K_{i,t+1}^v = (1 - \delta)K_{i,t}^v + I_{i,t}^v \quad (2.1)$$

⁵This paper can be found in Chapter 1 of this thesis.

where δ is the depreciation rate and $I_{i,t}^v \geq 0$ is the gross investment in vintage v .

The production technology in the consumption goods sector is represented by a Leontief type production function with complementarities between the qualities of the different vintages of the investment good and the specific skill level of employees for using these vintages. Vintages are deployed for production in descending order by using the best vintage first. For each vintage the effective productivity is determined by the minimum of its productivity and the average level of relevant specific skills of the workers. Accordingly, output for a consumption goods producer i at time t is given by

$$Q_{i,t} = \sum_{v=1}^{V_t} \min \left[K_{i,t}^v, \max \left[0, L_{i,t} - \sum_{k=v+1}^{V_i} K_{i,t}^k \right] \right] \cdot \min [A^v, B_{i,t}], \quad (2.2)$$

where $L_{i,t}$ is labor input, A^v is the productivity of vintage v and $B_{i,t}$ denotes the average specific skill level in firms as explained in more detail in Section 2.3.2.3. The fact that the considered production function takes into account the vintage structure of the capital stock and that firms select among different available vintages enables us to capture the effect of workers' skills on the incentives of firms to invest into new technologies (see Section 2.3.2.4).

Once every month each firm determines the quantities to be produced and delivered to each regional mall the firm is serving. Actual demand for the product of a firm in a given mall and a given month is stochastic (see below) and there are stock-out costs, because consumers intending to buy the product of a firm move on to buy from a different producer in case the firm's stock at the mall is empty. Therefore, the firm faces a production planning problem with stochastic demand and stock-out cost. The simplest standard heuristic used in the corresponding Operations Management literature prescribes to generate an estimation of the distribution of demand and then choose the planned stock level after delivery such that the (estimated) stock-out probability during the following month equals a given parameter value (which is influenced by stock-out costs, inventory costs and risk attitude of the firm (see, e.g., Silver et al., 1998)). Firms in the Eurace@Unibi model follow this simple heuristic, thereby generating a target production quantity for the considered month. Based on the target production quantity the firm determines the desired input quantities of physical capital and labor. Realizing this production plan might induce the need to buy new physical capital, hire new labor or to obtain additional credit. Although there is infinite supply of physical capital the firm might be rationed on the labor and credit market. In this case the firm accordingly adjusts its production quantity downwards.

2.3.2.2 Pricing Decision

Consumption goods producers set the price of their products once a year which is consistent with empirical observations (see, e.g., Fabiani et al., 2006). The pricing rule is inspired by the price setting described in Nagle et al. (2011, ch.6), a standard volume on strategic pricing in the Managerial literature. Firms seek for a profit-maximizing price taking into account the trade-off between price, sales and costs.

To obtain an indication of the effect of price changes on sales the consumption goods producers carry out *simulated purchase surveys* (see Nagle et al., 2011, pp. 304). A representative sample of households is asked to compare a firm's product with the set of the currently available rival products for a range of prices. Households' answers are based on the same decision rules they use for their real purchasing

decisions. Based on the resulting demand estimations and cost considerations firms choose the price which maximizes their expected discounted profit stream over their planning horizons.

2.3.2.3 Adjustment of Specific Skills of Workers

Each worker h has two dimensions of human capital endowments namely an exogenously given general skill level b_h^{gen} and an endogenously increasing specific skill level $b_{h,t}$. General skills can be interpreted as formal qualification or general embodied abilities while specific skills are experiences or abilities obtained on-the-job reflecting the productivity of each worker. For simplicity it is assumed that only two general skill levels exist $b^{gen} \in \{1, 2\}$, where b^{gen} refers to the general skill level. General skills are observable by firms in the hiring process while specific skills are not. They become observable during the production process. Acquisition of specific skills in the production is faster for the higher general skills. Formally, the workers increase the specific skills over time during production by a learning process. The speed of learning depends on the general skill level b_h^{gen} of the worker h and the average quality of the technology $A_{i,t}$ used by employer i :

$$b_{h,t+1} = b_{h,t} + \chi(b_h^{gen}) \cdot \max[0, A_{i,t} - b_{h,t}]. \quad (2.3)$$

Here $b_{h,t}$ are the specific skills of worker h in period t and $\chi(b_h^{gen})$ increases with general skills b_h^{gen} and $0 < \chi(b_h^{gen}) < 1$. The distribution of general skills in a region is deliberately kept exogenous in the model, since the effect of changes in this distribution is one of the key policy experiments in our analysis. Endogenizing the general skill distribution in a region would require an explicit representation of educational choices and the inclusion of an education sector, which would make the model much more complex and is beyond the scope of this paper.

2.3.2.4 Technological Change

The supply of the capital goods and the process of technological change are modeled in a very simplified way. We recur to a single capital good producer that offers different vintages of the capital good $v = 1, \dots, V_t$ that have distinct productivities A^v . Alternatively, our representation of the supply of capital goods can be interpreted as a market with monopolistic competition structure, where each vintage is offered by a single firm, which uses the pricing rule described below.

New vintages become available over time following a stochastic process. To avoid spurious growth effects, due to stochastic differences in the dynamics of the technological frontier between runs, we use identical realizations of the stochastic process governing the emergence of new vintages in all runs.

To keep the description of this sector as simple as possible, no explicit representation of the production process and of the needed input factors is introduced. To account for the cost dynamics, it is assumed that the main factor of production costs is the wage bill and, since wages increase on average with the same rate as productivity grows (see Section 2.3.2.6), the growth rate of productivity is used as a proxy for the increase in production costs of the capital goods.

The pricing of the vintages $p_{v,t}$ is modeled as a combination of cost-based p_t^{cost} and value-based prices $p_{v,t}^{value}$ (see, e.g., Nagle et al., 2011):

$$p_{v,t} = (1 - \lambda)p_t^{cost} + \lambda p_{v,t}^{value}. \quad (2.4)$$

Due to our assumption above, p_t^{cost} increases with the average productivity of the economy. For the value-based price component the average general and specific skills in the economy are determined first. In a next step the discounted productivities for each vintage are calculated for a firm that employs workers whose human capital is equal to the average of the economy. The value based part $p_{v,t}^{value}$ is proportional to this estimated effective productivity of the vintage. The motivation for this rule is that the capital good producer tries to estimate the value of each vintage, in terms of effective productivity, for its average customer. Furthermore, it is assumed that the capital good producer is able to deliver any demanded quantity of any vintage.

The reason why we choose such a simplified representation of the capital goods sector is our focus on the interaction of labor market and consumption goods market dynamics. Therefore, we try to keep all other sectors as simple as possible. Not explicitly modeling the hiring and firing decisions of the capital goods producer has two main implications. First, there are no wage payments from the capital goods producer to households. However, in order to close the model, all revenues of the capital goods producer are channeled back to the households through dividends on the index bonds. Second, the capital goods producer is never rationed on its input markets, in particular on the labor market. The qualitative implication of explicitly capturing the capital goods producer's hiring process would be that in periods when labor market tightness is high there would be a relatively high probability that the capital goods producer is rationed on the labor market. Being rationed the firm would not be able to deliver the full amount of capital goods that is demanded by the consumption goods producers. This would slow down the expansion of these consumption good producers relative to their plans. Such a qualitative effect is already present in the model since consumption good producers need to hire labor themselves whenever they want to expand their production. Through this channel a tight labor market has already a hampering effect on firms' expansion and potential rationing of the capital goods producer would not add a qualitatively different effect.

2.3.2.5 Investment and Vintage Choice

If consumption good producers have a target output level which cannot be produced with their current capital stock, they acquire new capital. To this end, a consumption goods firm has to choose from the set of available vintages. For the decision in which vintage to invest the complementarity between specific skills and technology plays an important role: due to the inertia of the specific skill adaptation, the effective productivity of a vintage with $A^v > B_{i,t}$ is initially below its quality. It converges to A^v over time as the specific skills of workers at the firm catch-up to the quality of the vintage. Therefore, the firm computes a discounted sum of estimated effective productivities over a fixed time horizon S . The specific skill evolution is estimated for each time step within $[t, t + S]$ using (2.3), where the firm inserts its average general and specific skill values. A logit choice model based on the ratio of the estimated effective productivity and price for each available vintage determines which vintage is ordered.

Investment goods are produced on demand, and as consumption goods producers may find it more suitable for their production plans not to employ the latest vintages, the investment good producer keeps on delivering also older vintages as the technology frontier grows. Note, that the way we model the investment good producer it is a proxy for a more differentiated market with different firms supplying different vintages. In this sense, we capture vertical differentiation in the supply of investment goods. Having an elaborated vintage supply is crucial for our con-

tribution given that the dynamics of the model unfold through the interaction of heterogeneous labor and capital as inputs to competing consumption goods producers. In particular, our approach allows to capture the effects of the skill endowment in a region on the vintage choice of firms and therefore on local technological change, which is an important mechanism in our analysis.

2.3.2.6 Labor Market Interaction

If the current workforce of a firm is not sufficient to produce its target output, the firm posts vacancies for production workers. The wage it offers has two constituent parts. The first part is the market driven base wage $w_{i,t}^{base}$. The base wage is paid per unit of (expected) specific skills of the worker. If the firm cannot fill its vacancies and the number of unfilled vacancies exceeds some threshold $\bar{v} > 0$ the firm raises the base wage offer by a fraction φ to attract more workers, i.e.

$$w_{i,t+1}^{base} = (1 + \varphi)w_{i,t}^{base}. \quad (2.5)$$

The second part of the wage offer is related to an applicant's expected level of specific skills. Since the specific skills represent the (maximal) productivity of the employees the wage $w_{i,t}$ is higher for higher (expected) specific skills. For each of the general-skill groups the firm i offers different wages $w_{i,t,g}^O$ in period t . The wage offers are given by

$$w_{i,t,g}^O = w_{i,t}^{base} \times \min[A_{i,t}\bar{B}_{i,t-1,g}] \quad (2.6)$$

where $\bar{B}_{i,t-1,g}$ are the average specific skills of all employees with general skill g in the firm.

The underlying assumption of this determination of wage offers is that firms can observe general but not specific skills of job applicants. Therefore, they use the average specific skills of all employees with general skill g in the firm in order to estimate the specific skills of an applicant with general skill level g . A firm can observe the specific skill levels of all its current employees, however this information will not be transferred to a competitor in case a worker applies there. The wage setting rule used is a reduced form representation of the outcome of firm-level wage negotiations taking into account workers' expected productivity in the firm as well as workers' outside option. While one might think of other models of wage setting and hiring models, it is crucial for our analysis to capture the link between workers' wages and their productivity in the employer firm as well as the effect of labor market tightness on wages. Both aspects are captured in a parsimonious way in the current set-up.

An unemployed worker takes the wage offers posted by searching firms into consideration and compares them with his reservation wage $w_{h,t}^R$. An unemployed worker will only apply at a firm that makes a wage offer such that

$$(1 - c)w_{i,t,g}^O > w_{h,t}^R, \quad (2.7)$$

where $w_{h,t}^R$ denotes the reservation wage of the worker and $c \in [0, 1]$ captures the commuting costs. If workers and employers are in the same region we have $c = 0$. For simplicity it is assumed that workers commute to an employer outside their own region rather than moving to that region, which means, in particular, that the

worker consumes in his home region.⁶

The level of the reservation wage is determined by the current wage if the worker is employed, and in case of an unemployed worker by his previous wage, where the reservation wage declines with the duration of unemployment. The reservation wage never falls below the level of unemployment benefits. If the unemployed worker receives one or more job offers he accepts the job offer with the highest wage offer. In case he does not receive any job offers he remains unemployed.

In case the workforce of a firm is too large relative to its target output level, the firm adjusts its number of workers. Employees with low general skills are dismissed first as those workers need longer to learn working with more advanced vintages. Additionally, there is a small probability for each worker-employee match to be separated in each period. This should capture job separations due to reasons not explicitly modeled.

2.3.2.7 Consumption Goods Market Interaction

The consumption goods market is modeled as a decentralized goods market. Each local market is represented by a mall at which the consumption goods producers can offer and sell their products to their customers. While firms are free to serve all malls regardless their spatial proximity, households always choose the mall which is located in their region.

Households go shopping once a week and try to spend their entire weekly consumption budget for one good. The consumption budget is determined using a (piecewise) linear consumption rule according to the buffer-stock approach (see Allen and Carroll, 2001; Carroll, 1997). At the beginning of their shopping procedure they get information about the prices of all available goods at the mall, but they get no information about the available quantities. The decision which good to buy is described using a logit-choice model with strong empirical foundation in the Marketing literature (see, e.g., Malhotra, 1984). An important parameter in this respect is the coefficient of the price of a good in the logit choice function. This parameter, denoted as γ^C , governs the price sensitivity of consumers and therefore the intensity of competition between the consumption good producers. Qualitative features of the economic dynamics are substantially influenced by changes in this parameter. Therefore, we will check the robustness of our qualitative findings for variations of this parameter.

The consumption requests for the different goods are collected by the mall and, if the total demand for one good exceeds its mall inventory level then the mall has to ration the demand. In this case the mall sets a rationing quota corresponding to the percentage of the total demand that can be satisfied with the available goods. Each household receives the indicated percentage of the requested consumption good.

After the shopping activity, rationed households may still have parts of their consumption budget available. Those households have the opportunity to spend the remaining budget for another good in a second shopping loop. In this case the

⁶Empirical evidence shows that even if workers move to the region of their employer a considerable part of their wage income is consumed in their home region due to remittances sent back. This holds, in particular, for workers from low productivity countries which recently joined the EU. In its report on employment and social conditions the European Commission (2011) informs that for the new EU member states received remittances amount to at least 1.7% of GDP on average per year [p.277]. Percentage-wise this almost matches the net population outflow from these countries of 2.1% (between 2003 and 2010) [p.252]. This clearly suggests that a large fraction of the income of the emigrants from these countries are channeled back as remittances.

shopping process is repeated as described above.

The production of the consumption goods firm follows a fixed time schedule with fixed production and delivery dates. Even if the mall stock is completely sold out it can only be refilled at the fixed delivery date. Consequently, all the demand that exceeds the expected value of the monthly sales plus the additional buffer cannot be satisfied.

2.3.3 Parametrization and Validation

The aim of our parametrization and validation of the model is to establish confidence in the ability of the model to capture economic mechanisms which are relevant for real world economic dynamics. For parametrization we follow an approach that combines direct estimation of parameters, for which empirical observations are available, with an indirect calibration approach. Standard constellations have been identified, where values of parameters are chosen to reflect empirical evidence whenever possible and where a large set of stylized facts can be reproduced. Furthermore, the fact that the development of the Eurace@Unibi model follows as far as possible the Management Science approach, briefly discussed above, provides empirical grounding to individual decision rules, thereby addressing the important point of empirical micro-foundations for modeled behavior.

The set of macroeconomic stylized facts that have been reproduced by the standard constellations of the Eurace@Unibi model includes persistent growth, low positive inflation and a number of important business cycle properties: persistent fluctuations of output; pro-cyclical movement of employment, consumption and investment, where relative sizes of amplitudes qualitatively match those reported e.g. in Stock and Watson (1999), counter-cyclical movement of wages and firm mark-ups. On the industry level the model generates persistent heterogeneity in firm-size, profit rates, productivity and prices in accordance with empirical observations reported e.g. in Dosi et al. (1997). Also labor market regularities, like the Beveridge curve, are reproduced by the model with benchmark parameter constellations. The reader is referred to Dawid et al. (2012b) for a more detailed discussion of this issue. Tables with the list of parameter values used in the simulations underlying this paper are provided in the Online-Appendix.

2.4 Policy Analysis

2.4.1 General Setup, Method of Policy Evaluation, Policies Considered

Our policy experiments are concerned with the convergence between a high tech and a low tech region in a two-region version of the model described above. Table 2.1 summarizes the initializations of the key variable for the two distinct regions R1 and R2. At time $t = 0$ the quality of the capital stock in the high tech region R1 is set to 1.5, and to 1.0 in the low tech region. The choice of the (adapting) specific skills corresponds initially to the quality of the capital stock. In R1 80% of the workers have high general skills, and the remaining part has low general skills. For R2 the general skill distribution is inverted. The technological frontier at $t = 0$ is set to a

Table 2.1: Initialization of capital stock and skills

	Region 1 (R1): high tech	Region 2 (R2): low tech
Initial quality of capital stock	1.5	1.0
Initial specific skills	1.5	1.0
General skill distribution	0.8/0.2	0.2/0.8

quality of 1.7 and afterwards grows at an annual rate of 1.8 percent.⁷

There is an initialization period of 10.000 iterations to avoid that results are driven by transient adjustment processes due to the initial conditions imposed. During the initialization period the technological frontier does not evolve, firms only have the option to buy the vintage with their initial technology, the consumption goods market is open and the labor market is closed.

For any considered parameter setting the initialization period is run once and all runs in the policy experiments start with the identical snapshot of the economy after the initialization period. In the policy analysis we mimic the European Union integration policies by introducing a subsidy scheme that influences firms' investment incentives, and by altering the general skill distributions in the two regions. More specifically, we are running two policy experiments:

1. In what we are going to call the Human Capital Policy (HC) the general skill level of R2 is upgraded to the general skill level of R1.
2. In what we are going to call Technology Policy (Tech) firms' investments in R2 are subsidized if equipment is bought from the technological frontier.

A more detailed description of the two policies is given below. Both the HC-policy and the Tech-policy are applied to two scenarios. In one scenario labor markets in the two regions are fully integrated. This means that workers face only small commuting costs ($c = 0.05$). In the second scenario, labor markets are separated implying that working in the region other than the own residence region causes prohibitively high commuting costs ($c = 1$).

In each of the two scenarios ($c = 0.05$ and $c = 1$) we consider three treatments in addition to the base scenario: only HC-policy, only Tech-policy and both policies. For each of the four cases 15 runs are conducted, with each run encompassing 750 months. The time series are pooled and the policy effects are estimated using penalized spline methods (see, e.g., Kauermann et al., 2009). More technically, the isolated effects and the interacted effects of the policies are evaluated with

$$Y_{t,p,i} = s(t) + I_{[p(HC)=1]}s_{HC}(t) + I_{[p(Tech)=1]}s_{Tech}(t) + I_{[p(HC)=p(Tech)=1]}s_{Int}(t) + \eta_i^0 + \eta_i^1 t + \varepsilon_{t,p,i}, \quad (2.8)$$

where $Y_{t,p,i}$ is the outcome variable at iteration t , for policy p , and run i . The baseline spline is $s(t)$ to which the policy splines are added with dummy variables I indicating if the policy is turned on or off. The linear term involving η_i^0 and η_i^1 captures run-specific random effects and $\varepsilon_{t,p,i}$ is the error term. The standard deviation of the

⁷Although we do not have a particular pair of countries in mind for the simulation analysis, the choice of the relative closeness of the two regions to the technological frontier follows the findings in Growiec (2008) who compares the production possibility frontier of Germany and Poland, and the estimates for productivity growth for Germany in the nineties as documented in Deutsche Bundesbank (2003).

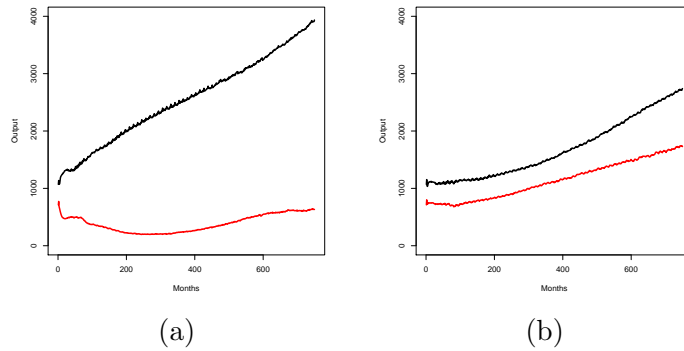


Figure 2.1: The evolution of output (a) integrated labor markets, (b) separated labor markets (black line: R1; red line R2)

spline estimates will also be plotted in the figures in order to illustrate significance of the different policy effects over time.⁸

2.4.2 Baseline Simulation With No Policies

With no policy treatment we get output trajectories as shown in Figure 2.1. The left panel refers to an integrated labor market and the right hand panel to a separated labor market with high commuting costs. There is no difference in the initial output level gap between the two regions across the two scenarios. As time elapses, however, completely different growth patterns emerge. For the high tech region R1 (black line) output grows constantly and almost quadruples until the end of the simulation period. The low tech region R2 (red line) experiences a drop in output and eventually recovers showing relatively low output growth. Overall, there is strong divergence of regional output levels. With separated labor markets, output increases in both regions but output growth is stronger in the high tech region, again leading to diverging output levels, although less extreme than in the integrated labor market scenario. Toward the end of the simulation output is lower in region 1 and higher in region 2 for closed labor markets as compared to integrated labor markets. Looking step by step into the evolution of the technologies, prices, and labor flow patterns will reveal the economic mechanism behind the results for the baseline simulation with no policies.

Figure 2.2 plots the trajectories for the exogenously evolving technological frontier, and the average technology used by firms for the two regions. Again, the left panel refers to an integrated labor market and the right panel to separated labor markets. For integrated labor markets, the gap between the technological frontier and average technology employed by firms for region 1 (black line) increases over time. As the gap stays approximately constant for region 2, average quality of technology employed in region 2 approaches that in region 1. For separated labor markets, region 1 stays closer to the technological frontier than with integrated labor markets. Moreover, region 2's technology gap to the frontier is increasing so that in

⁸All figures are based on estimations using the R function *gamm()* from the package *mgcv* (see, e.g., Wood, 2011). Although residuals in our estimation show some autocorrelation we abstain from estimating a computationally much more intensive and less stable model with AR(p) structure of the noise terms. Krivobokova and Kauermann (2007) have shown that the spline estimations are robust with respect to misspecified correlation structures, and therefore no qualitative changes of our results should be expected even if a model with more elaborated correlation structure would be used.

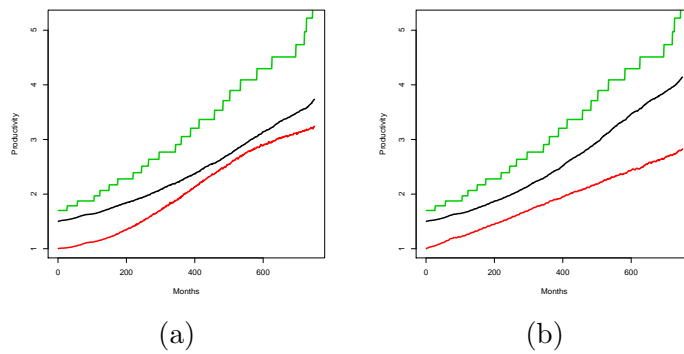


Figure 2.2: The evolution of technologies (a) integrated labor markets, (b) separated labor markets (green line: technological frontier; black line: average technology used in R1; red line: average technology used in R2)

this scenario the technological advantage of the firms in region 1 increases over time. Average technology actually used is closely related to the evolution of the output levels shown before.

The catch-up of average quality of technology employed in region 2 in the scenario of integrated labor markets is a consequence of two factors, which are both driven by the strong (initial) reduction in output produced in region 2. First, as can be seen by considering the dynamics of the distribution of firm output in a region (not reported here), the downturn in region 2 has a strong selection effect in that region. Only a few firms survive, namely those that due to early high vintage choices have the best capital stocks, and they produce only small quantities. Those firms in region 2 which have a capital stock of relatively low quality disappear from the market because the wages they have to offer in order to attract workers are too high relative to their effective productivity. This induces that the prices these firms charge are too high to be competitive. The second factor is that, given the low total output in region 2, the few surviving firms only use the qualitatively more advanced vintages. Whereas firms in region 1, given relatively high output, make also use of the older vintages, which reduces the average quality of technology. Thus, the relatively high quality of the capital stock in region 2 for integrated labor markets is a consequence of firm selection and the loss in aggregate demand for firms in this region which, as we explain now, is driven by relative prices that change due to labor market flows.

Output patterns can be traced down to relative demand for products produced in region 1 and 2. These relative demands are a function of the relative prices that firms from region 1 and 2 charge. As Figure 2.3 reveals, prices of products from region 2 are higher than those from firms in region 1 for the open labor market scenario, which explains the strongly diverging output patterns. With labor costs making up a considerably large share of production costs, and prices being set as a mark-up on unit costs, we can relate the price pattern to the labor flows which arise as regional labor markets are opened. Figure 2.4 plots numbers of workers with low general skills (left panel) and high general skills (right panel) for integrated labor markets. One sees, that there is a significant drop in the number of workers, both high skill and low skill, in region 2. Early on firms in region 2 have to increase their base wage offer in order to attract workers in spite of the lower productivity implied by the lower quality of their capital stock. This increases their unit costs and further deepens their competitive disadvantage. However, starting approximately at month

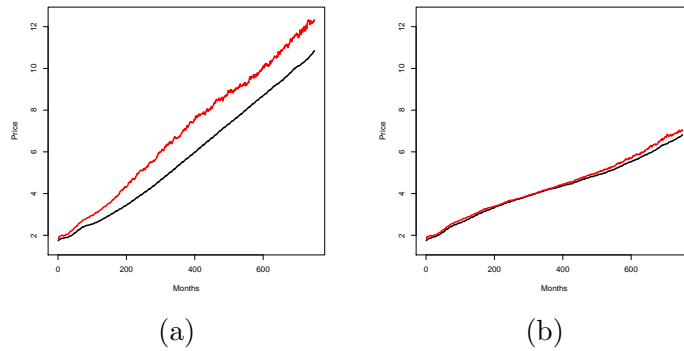


Figure 2.3: The evolution of mean prices (a) integrated labor markets, (b) separated labor markets (black line: R1; red line R2)

150, the few firms in region 2 have reached a wage level that enables them to attract more and more high general skill workers. This reinforces their incentives to invest in high vintages and they are able to close the gap to region 1 with respect to the quality of their capital stock. Eventually, at about period 400 the need for additional base wage increases vanishes for firms in region 2 due to the positive evolution of the productivity and the diverging pattern between the regions with respect to prices stops. Output produced and sold by the firms in region 2 starts increasing and the growth of the output gap between the regions becomes smaller (see Figure 2.1 (a)). The return movement of low skilled workers induced by this expansion in region 2 however then negatively affects the skill mix in region 2, which reduces incentives for firms to invest in new technologies. This stops the technological catch-up process by region 2 and the output gap increases again.

As can be seen in panel (b) of Figure 2.3, for separated labor markets the productivity advantage of firms in region 1 does not translate to a competitive advantage for this region. In this scenario wages in region 2 stay below the level in region 1 such that unit costs in both regions are approximately equal. The observation that nevertheless total output produced in region 1 is higher than that produced in region 2 can be explained by the larger production capacity of firms in region 1. The initial advantage of region 1 in this respect is never eliminated in the absence of a price advantage of either of the two regions. The costs for firms in region 2 associated with an expansion of their capacity would be so high such that an induced competitive disadvantage would result for these firms. Due to the pricing and production planning rules of the firms they realize this and abstain from expansion such that the initial capacity advantage for region 1 (which stems from the larger productivity of capital in that region) is cemented.

Overall, the baseline simulations show that in the absence of any cohesion policy measures region 2 does not catch-up to region 1 either with respect to output or to technology in both considered labor market scenarios.

2.4.3 Effect of Human Capital Policy

First we examine the dynamic effects of the human capital policy. We assume that the policy is implemented at the point in time where the two regions enter their economic union ($t = 0$), but, since the build-up of human capital takes time, the effects of the policy become apparent only after a delay of ten years. At $t = 120$

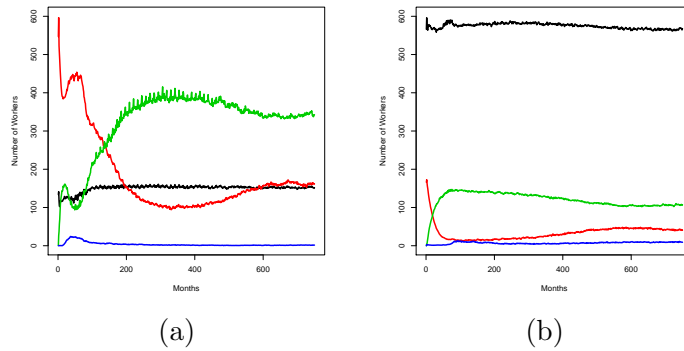


Figure 2.4: Commuters for integrated labor markets (a) low general skill, (b) high general skill (black line: workers from R1 working in R1; red line: workers from R2 working in R2; blue line: workers from R1 commuting to R2; green line: workers from R2 commuting to R1).

the distribution of general skills in region 2 becomes identical to that of region 1.⁹ Clearly the assumption that the gap in general skills can be completely closed by the human capital policy within ten years is very strong, but since we are mainly interested in understanding the qualitative differences in the policy effects in different economic environments, an exact quantification of the policy strength is of minor concern to us.

Figure 2.5 shows the effect of the HC-policy output in both regions for integrated and separated labor markets as estimated by the penalized spline model discussed above (i.e. we show the estimated splines $s_{HC}(t)$ in both scenarios). The policy effect is strikingly different, depending on whether the labor market is integrated or not. With an integrated labor market the effect on output in the target region 2 is negative, whereas output in region 1 is positively affected. These effects are not transitory, rather they seem to become more substantial as time evolves. A very different picture emerges in the scenario with separated labor markets. In this case the policy has no significant effect for an initial time interval ($t = 120$ to approximately $t = 200$), but afterward leads to an increase in the output produced in region 2, whereas the output in region 1 is negatively affected. Aggregating over both regions it can be observed that the effect of the HC-policy on total output in both regions is positive, and that the effect is much stronger if labor markets are separated. Hence, spatial frictions, preventing the free allocation of workers across regions, positively affect the overall effects of this policy.

The negative output effect of the HC-policy in region 2 arises from two counter-vailing forces. As intended by the HC-policy improving the workers general skills has a positive effect on firms productivity through the vintage choice. Firms in region 2 become more productive due to easier access to workers with high general skills. Figure 2.6 depicts the estimated effect of the HC-policy on the ratio of average vintage choice and general skills, respectively, between firms in region 2 and region 1.¹⁰ The two lines (plus standard deviation bands) in each panel describe the effects of

⁹For reasons of simplicity it is assumed that all individuals upgrade their skill exactly at $t = 120$. A more gradual skill upgrading over time would be more realistic, but would not qualitatively alter the effects we identify. The set of individuals who upgrade their skill is selected randomly.

¹⁰Technically speaking equation (2.8) is estimated for $Y_{t,p,i} = \frac{\bar{v}c_{t,p,i}^2}{\bar{v}c_{t,p,i}^1}$, where $\bar{v}c_{t,p,i}^r$ denotes the average vintage choice at time t of all firms in region r in run i under policy p .

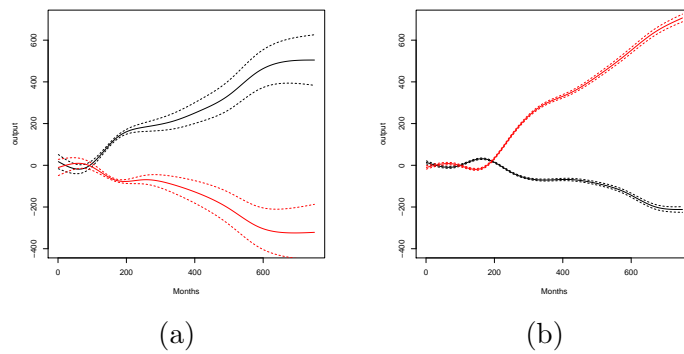


Figure 2.5: The effect of the human capital policy on output for (a) integrated labor markets, (b) separated labor markets (black line: R1, red line: R2).

the policy in the scenario with integrated and separated labor markets, respectively. A positive sign of the estimated effect means that due to the HC policy the average value of the considered variable in region 2 has increased relative to region 1. Panel (a) of this figure shows that the average vintage choice of firms in region 2 increases relative to the choice of firms in region 1 as a response to the HC-policy. The policy effect is, furthermore, larger for separated than for integrated labor markets. However, the policy sparks another indirect mechanism that overcompensates the positive effect on vintage choices so that the overall effect on investment becomes negative. Let us turn to this more involved second effect now.

As the policymakers improve general skills in region 2, the relative endowment of region 2 with high general skills improves. This is less so if labor markets are integrated, see Figure 2.6 (panel (b)), because high skilled workers from region 2 get job offers from firms in region 1 that net of commuting costs improve their earnings. High skilled workers from region 2 therefore eventually work in region 1. As a result, firms in region 2 have problems filling their vacancies. They start making higher wage offers. Figure 2.7 (panel (a)) shows that wage offers of firms in region 2 relative to wage offers of firms in region 1 increase as a response to the HC-policy for integrated labor markets. It decreases for separated labor markets as the HC-policy increased the supply of high skilled workers in region 2 relative to region 1. As labor costs constitute a considerable share of firms' production costs, unit costs for firms in region 2 relative to region 1 increase for integrated labor markets, and decrease for separated labor markets, see panel (b) of Figure 2.7. The unfortunate effect on relative unit costs for region 2 with integrated labor markets ceases around period 500. However, firms in region 2 react to the alignment of costs between the two regions by an increase in mark-ups rather than by a decrease in price (see panel (d) of Figure 2.7). The reason for this is that firms in region 2 anticipate that the expansion corresponding to substantial own price decreases would be associated with considerable investments (which are not needed by the firms in region 1, which already have larger production capacities) and hence maximization of their estimated discounted profit streams yields substantial increases in mark-ups when their costs converge toward those of firms in region 1. Overall, region 2 suffers from a loss of competitiveness as a result of the improvement of the skills of its labor force when labor markets are integrated. Charging higher prices than firms in the competing region 1, firms in region 2 are losing demand. As lower output is produced also investments and the diffusion of new vintages decrease so that the

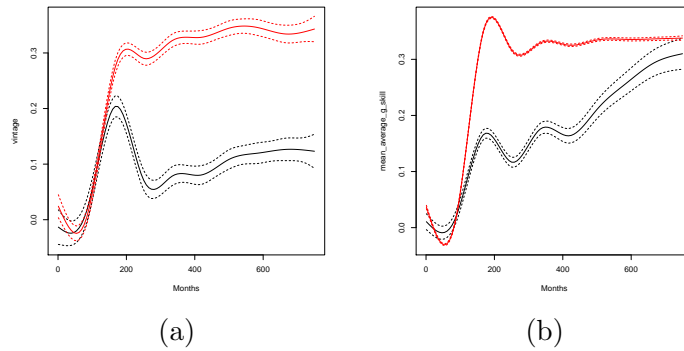


Figure 2.6: The relative effect of the human capital policy on (a) vintage choice and (b) general skill mix, computed as the effect on the ratio of variable values from Region 2 to that from Region 1 (black line: integrated labor market, red line: separated labor markets).

overall effect on the productivity weighted capital stock¹¹ is negative in the region at which the policy is targeted for integrated labor markets (Figure 2.8 (a)). The observation that due to labor flows a policy improving the general skills of (local) inhabitants might have negative effects on growth in regions where productivity is relatively small is consistent with empirical results reported in Aghion et al. (2009).

Summarizing, we observe that the HC-policy only has the intended effect of fostering convergence if the spatial labor market frictions are large. In case that labor is mobile across borders the policy has detrimental effects for the target region 2 with respect to output and technological development since the indirect negative effect stemming from the deterioration of the relative competitiveness of region 2 firms dominates the direct positive effect on vintage choices induced by the skill upgrading of the local labor force.

2.4.4 Effect of Technology Policy

Quite a different picture emerges compared to our discussion in the previous subsection if we consider the implications of the Tech-policy. Under the Tech-policy a firm which invests in physical capital of the highest vintage that is available at the time of the purchase receives a public subsidy in the amount of 5% of its investment. When deciding about their vintage choice firms take that subsidy into account. In their vintage choice rule the price is reduced for the vintage on the frontier accordingly. This distorts the vintage choice of firms in the target region in favor of the best available vintage. As can be seen in Figure 2.9 by adding up the splines capturing the policy effects in the two regions, total output in the economy increases. However, a targeted technology policy leads to an increase in output produced in region 2, no matter whether the labor market is integrated or separated. The effect is much stronger if labor markets are integrated and in this scenario there is a significant negative effect on output in region 1, which is not present under separated labor markets.

For separated labor markets the effects of the Tech-policy are qualitatively very similar to the effect of the HC-policy. The two policies are close substitutes. This

¹¹The productivity weighted capital stock is a measure that captures the size and the quality of the capital stock of a firm. It is computed as a weighted sum of the capital with vintage specific productivities A^v used as weights, i.e. $\sum_{v=1}^{V_t} A^v K_{i,t}^v$.

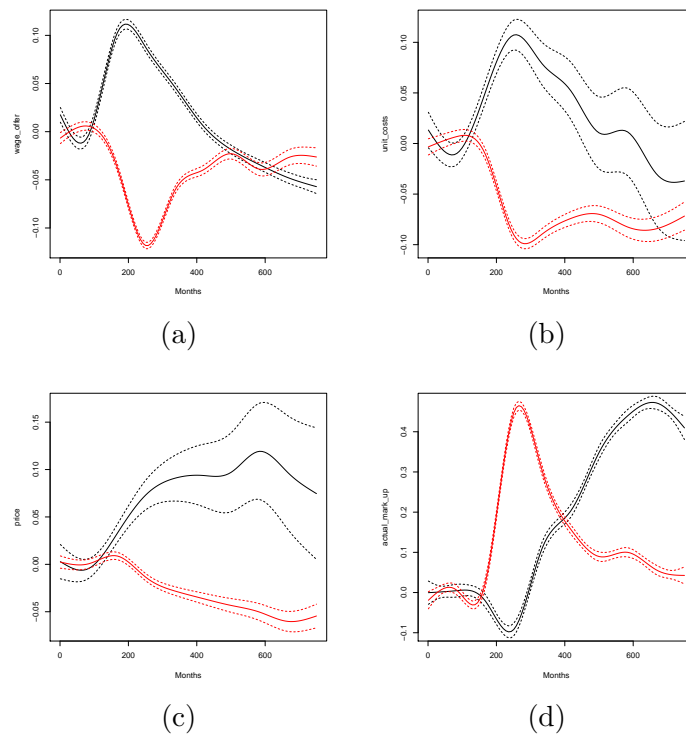


Figure 2.7: The relative effect of the human capital policy on (a) base wage offers, (b) unit costs, (c) prices and (d) mark ups, computed as the effect on the ratio of variable values from Region 2 to that from Region 1 (black line: integrated labor market, red line: separated labor market)

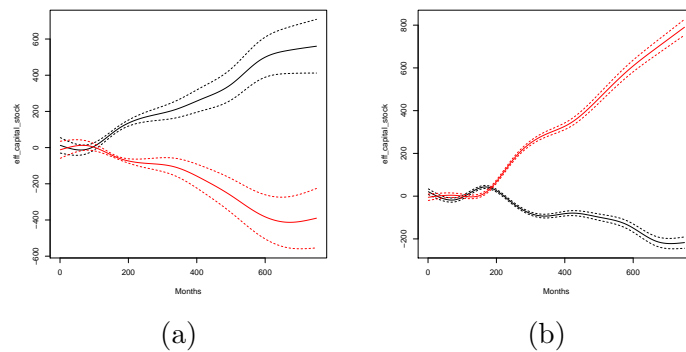


Figure 2.8: The effect of the human capital policy on the productivity weighted capital stocks for (a) integrated labor markets, (b) separated labor markets (black line: R1, red line: R2).

holds not only for the output dynamics, but also for variables like quality of capital, vintage choice and price. In our discussion we will, therefore, concentrate on the effects of the Tech-policy under integrated labor markets.

Figure 2.10 shows for this scenario the implications of the introduction of a Tech-policy for the dynamics of ratios between region 2 and region 1 for vintage choice, average quality of capital, general skills, as well as the average price of the consumption goods. The direct effect of the policy, namely an increase in the

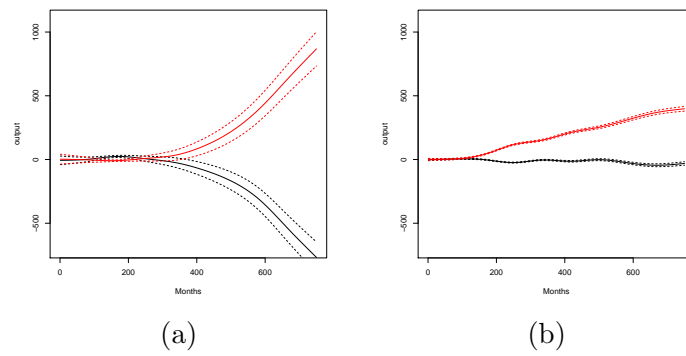


Figure 2.9: Effect of the Tech-policy on output in region 1 (black line) and region 2 (red line) for (a) integrated labor markets and (b) separated labor markets.

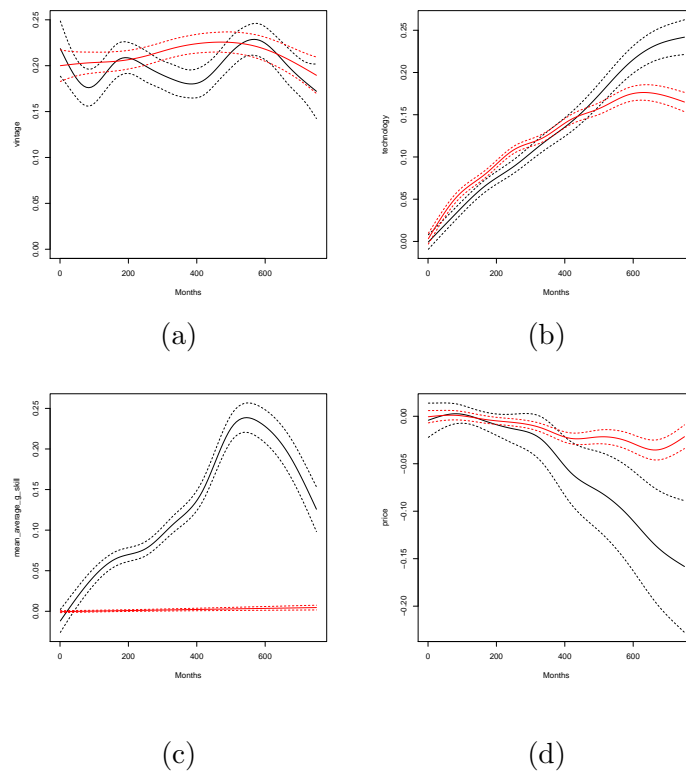


Figure 2.10: The relative effect of the technology policy on (a) vintage choice and (b) average quality of the capital stock and (c) general skills of workers employed in a region and (d) average price posted by firms, computed as the the effect on the ratio of variable values from Region 2 to that from Region 1 (black line: integrated labor market, red line: separated labor market)

vintage choice of firms in region 2, can be clearly seen in panel (a) of this figure. In particular, this figure shows that the vintage choice in region 2 goes up relative to that of region 1, which means that the gap in terms of quality of newly acquired machines is reduced. As shown in panel (b) this results in an increase in the relative quality of the capital stock used by firms in region 2. The improvement of the quality of the capital stock induces that firms in region 2 are better able to keep workers with high general skills in their region (see panel (c)), such that the technology

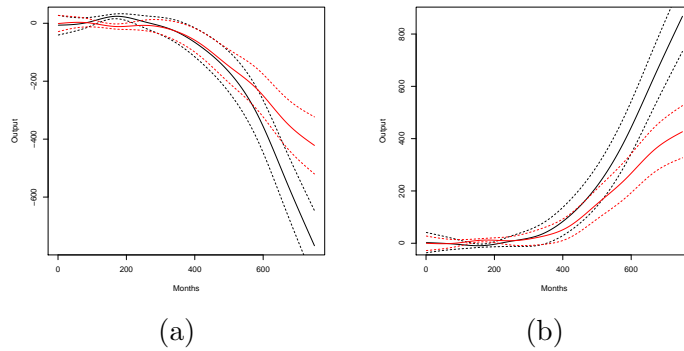


Figure 2.11: Comparison of the effect of the targeted (black line) and non-targeted (red line) Tech-policy on output in (a) region 1 and (b) region 2, for integrated labor markets.

policy also has a positive effect on the human capital stock in region 2. This policy, although not explicitly targeted at human capital upgrading, is able to improve the level of human capital employed in region 2 relative to region 1. Also in this respect the policy performs better than the HC-policy whose explicit aim is to improve the human capital endowment in region 2. The improved quality of physical and human capital employed in region 2 leads to a reduction in the price gap between the two regions (panel (d)) and thereby improves the competitiveness of region 2 leading to the observed positive effect on output produced by region 2 firms. The higher competitiveness of region 2 comes at the expense of firms in region 1, whose output actually goes down. Considering the isolated effect of the policy on region 1 variables shows a negative effect on vintage choice and average capital quality for that region, which is due to the increase in attractiveness of high vintages for region 2 firms, thereby inducing an increase in relative prices of these vintages.

The technology policy considered in our analysis so far is targeted, in a sense that firms only receive price subsidies if they acquire the highest available vintage. In practice such a targeted policy might be difficult to implement, since it is not easily verifiable whether an acquired machine is indeed at the technological frontier of the considered industry. Hence, one might wonder whether it is essential that price subsidies are targeted to the best vintages. Similarly to the considered Tech-policy general investment subsidies could be introduced, where firms receive a 5% subsidy on all acquisitions of physical capital. Such a measure should foster investment, thereby inducing a faster diffusion of new technologies, as well as reduce firms' unit costs and costs of expansion, which should lead to lower prices and larger output by region 2 firms. Figure 2.11 shows however that such a policy has a much weaker effect on output in both regions. In the absence of the stimulation of high vintage choices in region 2 the quality of capital does not increase as much as under the targeted technology policy and the fraction of high skilled workers in the region is not as high. The competitive disadvantage of region 2 with respect to unit costs, which can be completely eliminated with a targeted technology policy is reduced but not eliminated with an untargeted version of the policy.¹² This shows that it is indeed important that investment subsidies are targeted in a way that the incentives of firms to acquire new vintages are increased.

¹²The time series data from simulations backing these observations are available from the authors on request.

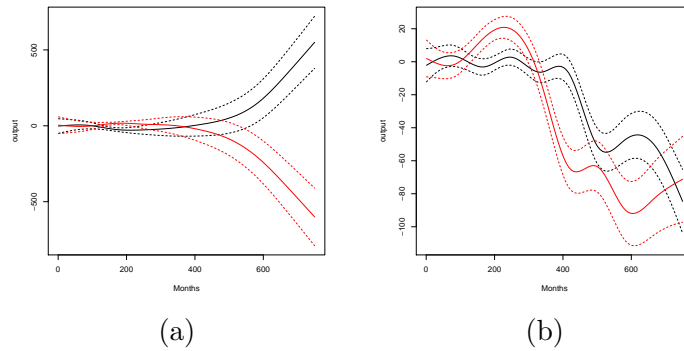


Figure 2.12: Comparison of interaction effects for (a) integrated and (b) separated labor markets. (black line region 1, red line region 2)

2.4.5 Interaction Effects

We conclude the analysis of the effects of HC- and Tech-policies on regional convergence by considering the interaction effects between the two policies. Intuitively, the relationship between the two policies is not obvious. Both aim at the improvement of the technological level, specific skills and productivity of firms in region 2 and, therefore, could be considered as substitutes. On the other hand, the complementarity between physical and human capital captured in our model suggests that the impact of each policy might increase if combined with the other one.

As can be seen in Figure 2.12 it indeed depends on the size of the spatial labor market frictions whether the interaction effect between the policies with respect to output in region 2 is positive or negative. For integrated labor markets the interaction effect is positive for region 1 but negative for the target region 2. The interaction effect becomes significant only after a delay of about 400 periods, which is due to the fact that the introduction of the Tech-policy affects output in the two regions only after a considerable delay (see Figure 2.9). In light of our discussion above about the effects of both policies under integrated labor markets this shape of the interaction effect is quite intuitive. In Section 2.4.3 it was pointed out that with an integrated labor market the HC-policy leads to a substantial reduction of investments in region 2 compared to the benchmark case without policy. This reduction in investment reduces the positive effect of the Tech-policy, which explains the negative interaction effect for region 2. Since firms in region 1 profit from this weakening of the increase in productivity of region 2 firms, we obtain a positive interaction effect in region 1. In the case of separated labor markets, as discussed above, both policies have a positive effect on output in the target region. Panel (b) of Figure 2.12 shows that there is a negative interaction effect, which in this scenario indicates a certain degree of substitutability between the policies. The intuition for this substitutive relationship is that the HC-policy already increases the incentives for firms in region 2 to invest in high vintages, which reduces the positive effect of the Tech-policy. Hence a negative interaction effect results.

2.4.6 Robustness of Qualitative Findings

Our discussion of the effects of the HC and the Tech-policy was based on simulations carried out for our default parameter setting and two labor market scenarios, namely

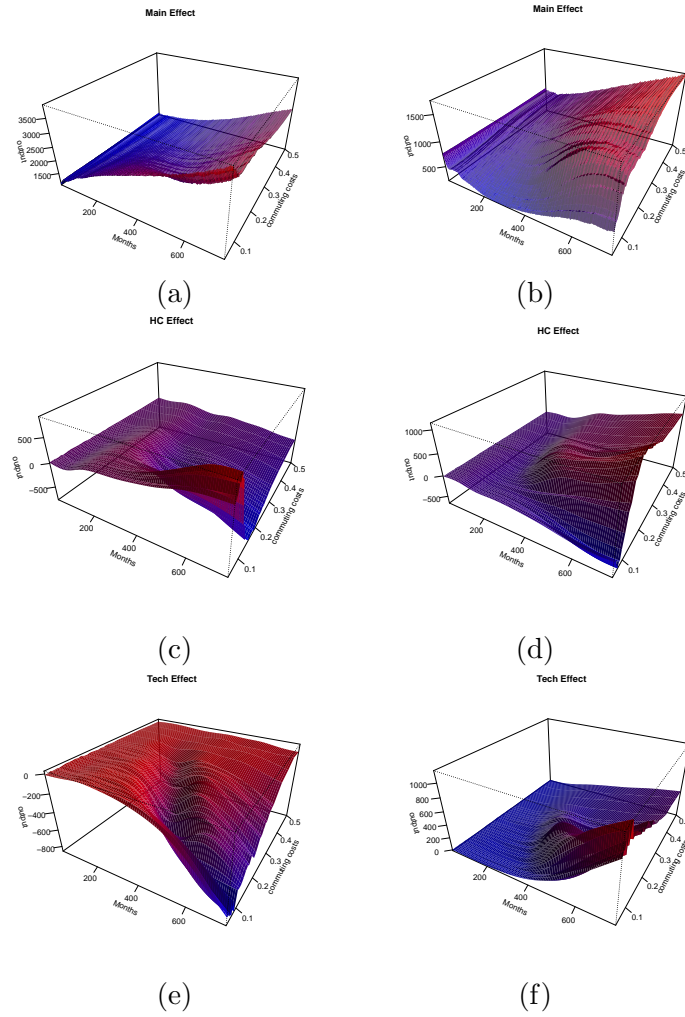


Figure 2.13: Effects of a variation of commuting costs on the evolution of output ((a) and (b)), the effectiveness of the human capital policy ((c) and (d)), and the effectiveness of the technology policy ((e) and (f)) in Region 1 (left column) and Region 2 (right column).

$c = 0.05$ and $c = 1$. We have carried out substantial robustness checks to confirm that the qualitative findings stay intact also if we vary the parameters within a reasonable range. The robustness of the results with respect to changes in the most important parameters are briefly discussed in this subsection.

In Figure 2.13 we show the spline estimates of the evolution of output without policy, of the impact of the HC policy, and the impact of the Tech-policy in the two regions for values of the commuting costs varying between $c = 0.05$ and $c = 0.5$. We restrict attention to this interval because $c = 0.5$ corresponds already to a de-facto separated labor market, and hence there are virtually no effects of varying c in the interval $[0.5, 1]$. To keep the graphs readable we abstain from showing the standard deviations for the shown spline estimates. From panels (a) and (b) it can be clearly seen that in the absence of policies the output in region 1 is monotonically decreasing and output in region 2 monotonously increasing with respect to the commuting costs for any considered time t , but the effect becomes much more pronounced in the long run. Considering the effect of the HC-policy the figure shows that the negative implications of the policy in the target region for the case of integrated labor markets

apply to values of the commuting costs up to approximately $c = 0.15$. In this range the effect for region 1 is positive as discussed above. Only for commuting costs above this level is region 2 positively affected by the policy, where the positive effects are strongest for a scenario where spatial labor market frictions are considerable, but markets are not fully separated. Also the qualitative findings concerning the effects of the Tech-policy are confirmed. The effect is positive in region 2 and negative in region 1, where the sizes of these effects decrease as spatial labor market frictions increase.

We have carried out numerous robustness checks with respect to variations of other parameters, in order to check whether the key qualitative findings – in particular the observations that the HC-policy has negative effects for integrated and positive effects for separated labor markets in the target region, whereas effects of the Tech-policy are always positive – stay intact. Robustness of this kind could be confirmed for all considered parameters. In the Appendix we present such robustness checks for five additional key parameters.

Finally, one may wonder whether our qualitative findings remain valid if the policies are financed by taxes raised in the economy and also whether the type of fiscal policy used influences the policy effects. Our current setup does not allow to fully address this issue because no market for the acquisition of general skills is modeled. Therefore, we lack a measure for how costly the upgrading of the general skills is in our policy experiment, which makes it impossible to introduce endogenous tax-based financing of the HC-policy. Nevertheless, no matter how the costs of the HC-policy would look like, the qualitative differences between effects of Tech- and HC-policies would not change in a version of the model with endogenous policy financing. In any case, endogenizing the financing of the discussed policies would be an interesting extension of the present paper.

2.5 Discussion and Conclusion

In this paper we have used the agent-based macroeconomic Eurace@Unibi model to analyze in how far two types of cohesion policies, which are inspired by measures applied by the European Union, are suitable to foster convergence between regions that differ with respect to their initial endowments in the quality of physical and human capital. We have shown that both types of policies have the intended effects as long as labor is sufficiently immobile. With integrated labor markets the human capital policy has detrimental output effects for the region at which the policy is targeted. Technology policy, implemented through subsidies for acquisition of physical capital is effective, and particularly so if the subsidy is targeted and only paid if firms invest in vintages at the technological frontier. Clearly, these findings bear strong policy implications suggesting that convergence may be better achieved by a change in the policy mix taking into account that human capital policies will less likely contribute to the convergence of regions as labor market integration is intensified. Moreover, it suggests that technology policies need to be accompanied with measures to improve absorptive capacities of the targeted regions to make sure that capital from the technological frontier is subsidized.

We have explored the mechanisms underlying the different policy effects and shown that these effects are driven by the interplay of firms' vintage choices and investment decisions. While the former is a straightforward and expected outcome of the policies, the latter is the product of an economic mechanism resulting from the cohesion policies that affect the evolution of relative output through changes in

regions' competitiveness which in turn result from the dynamics of the (general and specific) skill levels of workers in the two regions. It turns out that for HC-policies the indirect effect on investments arising through the reduction in the regions' competitiveness is so strong that the policy has a negative effect on (productivity weighted) capital stock and output in the target region for integrated labor markets.

To put these findings into perspective it should be pointed out that firms in the two regions are actually identical in many respects. The firms share the same production functions, households share the same rules determining their savings, their consumption decision etc. and apart from the subsidies introduced in the framework of the Tech-policy the public (fiscal) policies are the same in both regions. In the baseline scenario the two regions differ only with respect to the initial quality of the physical capital stock, with respect to the initial distribution of specific skills in the two regions and with respect to the general skill distributions. Since the first two of these three items refer to initial values of endogenous variables of the model, the only structural difference between the two regions is the difference with respect to general skills.

This asymmetry disappears once the HC-policy, which makes the general skill distribution in region 2 equal to that of region 1, is introduced. Considering the long run equilibrium balanced growth path of this two-region economy one would therefore expect that regardless of the spatial labor market frictions the two regions grow at the same rate. Furthermore, according to such an analysis, the effect of the HC-policy would always be positive for region 2 regardless of the amount of labor market frictions. The analysis in this paper also takes into account the short and medium run implications of the policies, which arguably for many issues is the most relevant time-frame for policy evaluation. We obtain much richer and more differentiated insights into the effects of the considered policy measures. In particular, the fact that the economic dynamics of the two regions is explicitly simulated allows to capture path dependencies, which in this framework are crucial for the understanding of the policy implications in the different considered scenarios. These path dependencies, which hinge on the interplay of firms' stocks of physical and human capital with their vintage choices, investment decisions and worker movements between firms, generate obstacles to overcome the initial regional asymmetry and leads to a diversion of positive policy effects from the target region toward the high tech region 1. Overall, these findings illustrate the merits of an agent-based approach for the analysis of effects of different policy measures and their combination in different time-frames.

2.A Appendix

2.A.1 Robustness Checks

In this appendix we show the robustness of our findings with respect to a variation of five specific parameters of the model. Two of which have a considerable impact on the simulation outcome. These two parameters, the price sensitivity of consumers and the speed of change of the technological frontier, have been identified in extensive experiments with the model as the parameters that have the largest impact on the qualitative properties of the simulation dynamics. Hence we report our robustness checks with respect to these two parameters here. Additionally, we show robustness checks for the depreciation rate of capital, the discount rate applied to the effective productivity of an investment good, and the replacement rate of unemployment

benefits. Effects of those three parameter variations turned out to be much weaker.

The first considered parameter specifies the price sensitivity in the consumption choice problem of households. The decision which good to purchase is modeled as a logit model where the probability to buy a particular good depends on its relative price. The weight of the price in the logit function, which can also be interpreted as the intensity of choice, is given by the parameter γ^C . Varying this parameter changes the strength of how households react to price changes and thus it determines the scope for price changes of individual firms and the overall competitiveness on the consumption goods market. In the experiment we use a value of $\gamma^C = 9.0$ that is associated with a medium level of competitiveness. For the robustness check this parameter is varied within a range between 7.0 and 11.0, which is a range in accordance with empirical estimations obtained for consumption good markets (see Krishnamruthi and Raj, 1988). Figure 2.14 shows how the variation of this parameter affects the evolution of the regional output in the initially less developed region 2 and how the variation of the parameter influences the effectiveness of the human capital and technology policy in this region. It can be clearly seen that the qualitative features worked out for the default parameter setting, namely that the effect of the HC-policy is negative for integrated and positive for separated labor markets, whereas the effect of the Tech-policy is positive in both labor market scenarios stay intact for the entire considered range of the parameter γ^C . An interesting additional observation is that the size of the negative respectively positive impact of the policies under an integrated labor market goes down if the consumption good market becomes more competitive. The intuition for this observation is that in such a strongly competitive environment the weaker region 2 shows almost no growth without policy (see panel (a)), which, on the one hand, means that there is little to lose by the ill-suited application of the HC-policy. On the other hand, even with the help of the Tech-policy, the growth in region 2 is very slow in the presence of the intensive competition of firms from region 1.

The second parameter with a strong impact on the simulations is the speed of technological change. As described in Section 2.3.2.4 the development of improved capital goods is the result of a stochastic process, where with an exogenously given probability a new vintage emerges whose productivity is improved by Δq^{inv} compared to the previous best practice technology. In the experiments, we use identical realizations of the stochastic innovation process in order to avoid spurious growth effects due to different dynamics of the frontier. To check the robustness of the policy analysis with respect to different speeds of technological growth, we keep using the same realization of the stochastic process determining the period when innovations take place, but vary the parameter for the productivity progress Δq^{inv} at each innovation step within a range of 0.0 and 0.07. Thereby, a value of 0.0 means no technological progress. In the policy experiments we use a value of 0.05 that translates to an average productivity growth of the frontier by 1.8% per annum. Figure 2.15 shows the impact on the output evolution and the policy effectiveness in region 2. Again, it can be clearly seen that all qualitative effects of the policies in the entire interval correspond to those observed in our default setting.

The remaining three parameters are the depreciation rate δ that was set to a monthly value of 0.01 in the simulations, the discount rate $\rho = 0.02$, and the replacement rate for unemployment benefits $u = 0.7$. For the robustness test we varied the monthly depreciation rate between 0.004 and 0.012. The range captures what national accounts report for capital depreciation rates. The monthly discount rate was varied between 0.005 and 0.04, and finally, the replacement rate was increased

from 0.6 to 0.8 which covers the range of typical net replacement rates for OECD countries. The results for the robustness checks for those three parameters are shown in Figures 2.16, 2.17, and 2.18, respectively. Figure 2.16 shows that for integrated labor markets and very low levels of capital depreciation the downturn in region 2 leads to an almost complete absence of investment in that region. Hence, both policy effects are very minor. Overall, the qualitative effects of the policies correspond to the ones which we report in our analysis where we use the default settings. In conclusion, variation of all five parameters suggests that our main findings are robust with respect to parameter specifications.

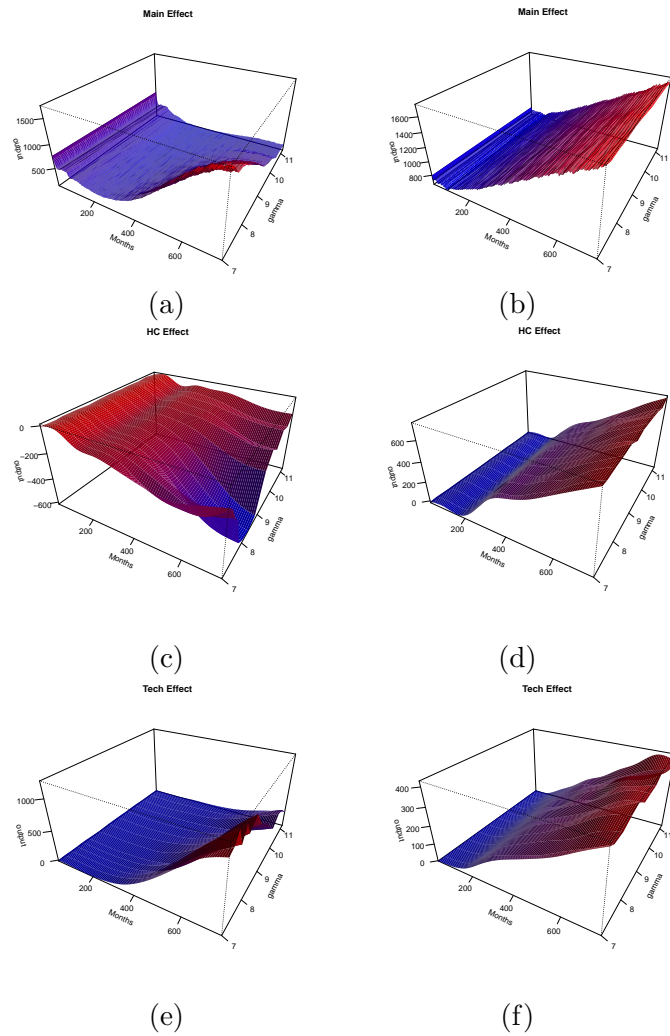


Figure 2.14: Effects of a variation of households' price sensitivity on the evolution of output without policy ((a) and (b)), the effectiveness of the human capital policy ((c) and (d)), and the effectiveness of the technology policy ((e) and (f)) in the lagging Region 2 for integrated (left column) and separated (right column) labor markets.

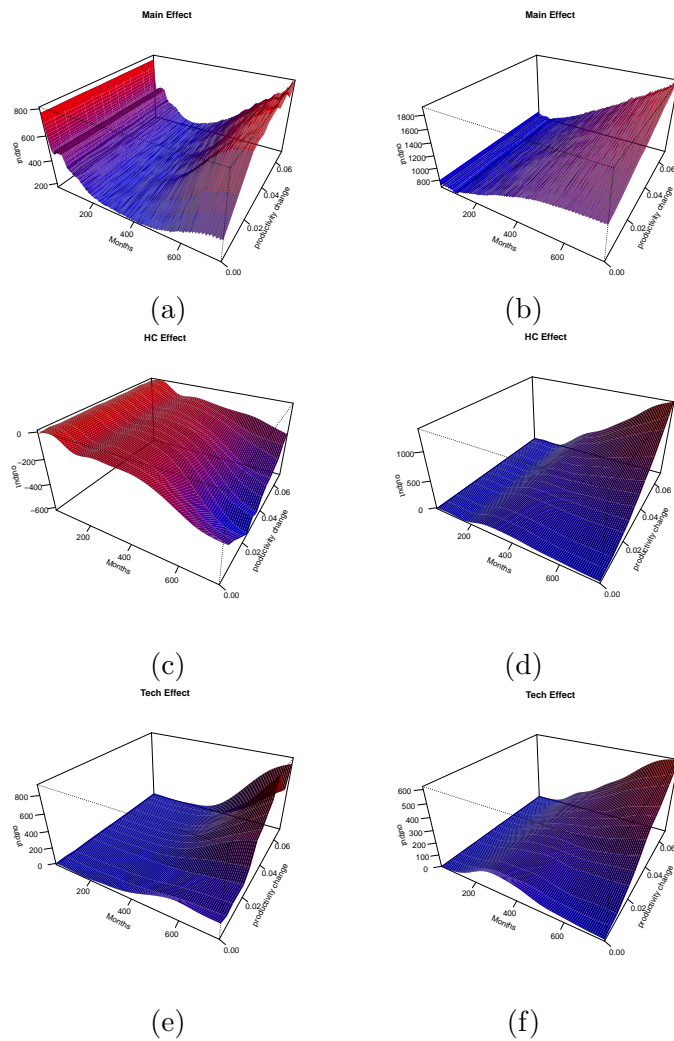


Figure 2.15: Effects of a variation of the speed of technological change on the evolution of output without policy ((a) and (b)), the effectiveness of the human capital policy ((c) and (d)), and the effectiveness of the technology policy ((e) and (f)) in the lagging Region 2 for integrated (left column) and separated (right column) labor markets.

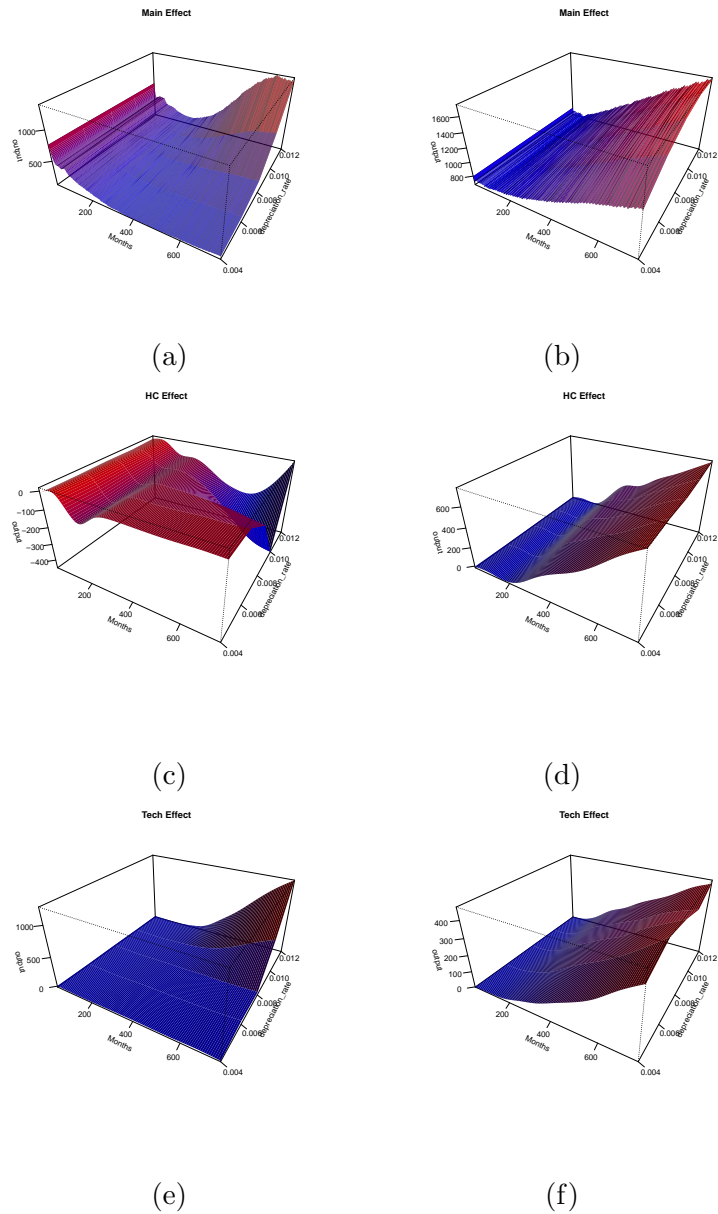


Figure 2.16: Effects of a variation of the depreciation rate on the evolution of output without policy ((a) and (b)), the effectiveness of the human capital policy ((c) and (d)), and the effectiveness of the technology policy ((e) and (f)) in the lagging Region 2 for integrated (left column) and separated (right column) labor markets.

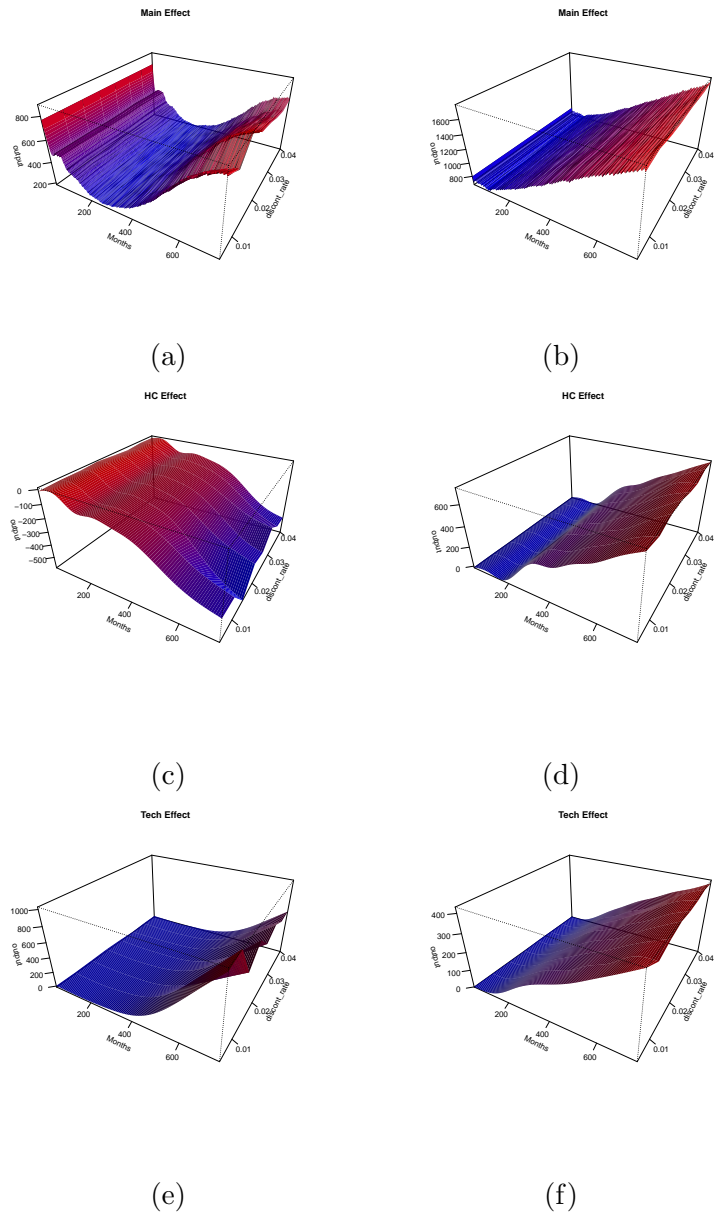


Figure 2.17: Effects of a variation of the discount rate on the evolution of output without policy ((a) and (b)), the effectiveness of the human capital policy ((c) and (d)), and the effectiveness of the technology policy ((e) and (f)) in the lagging Region 2 for integrated (left column) and separated (right column) labor markets.

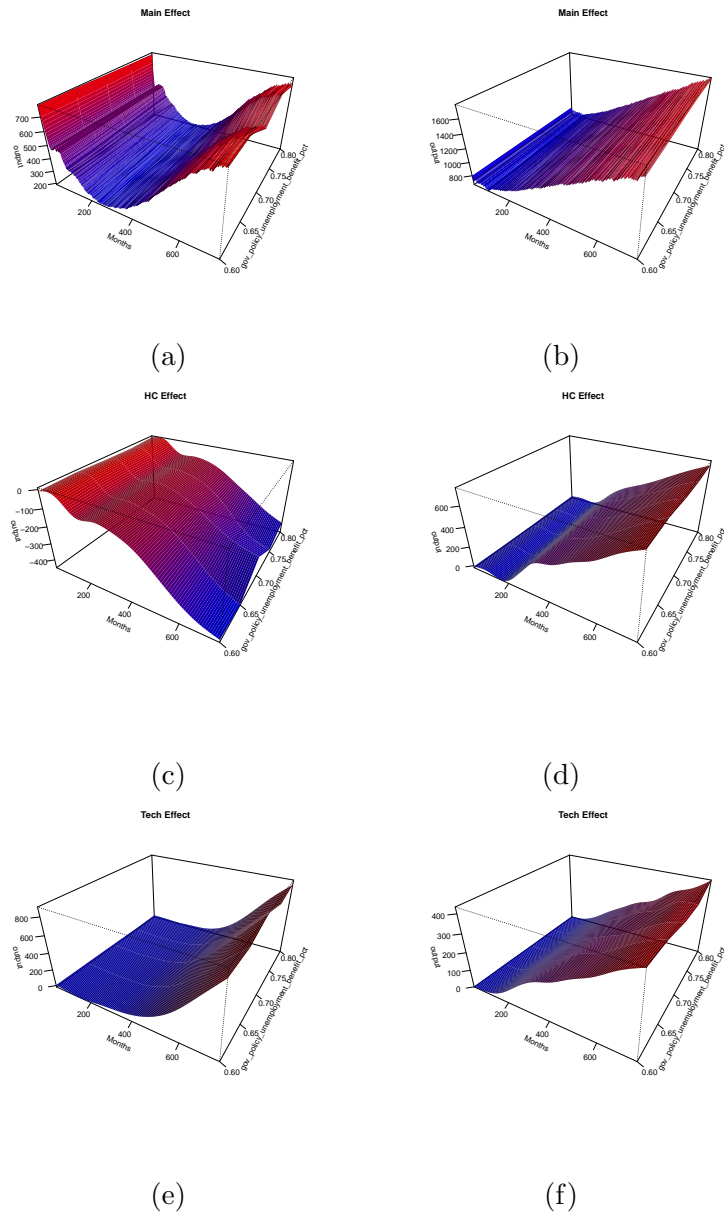


Figure 2.18: Effects of a variation of the unemployment insurance replacement rate on the evolution of output without policy ((a) and (b)), the effectiveness of the human capital policy ((c) and (d)), and the effectiveness of the technology policy ((e) and (f)) in the lagging Region 2 for integrated (left column) and separated (right column) labor markets.

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Chapter 3

Stabilization Policies and Long Term Growth: Policy Implications from an Agent-based Macroeconomic Model

3.1 Introduction

The recent world economic crisis marks the deepest downturn in the postwar era. Triggered by the subprime mortgage crisis in the United States that evolved into a world financial liquidity crisis, the recession affected the entire world economy, with greater detriment to some countries than others. According to OECD statistics, the U.S. economy declined by 3.5% from the first quarter in 2008 to the second quarter in 2009, whereas Japan recorded a contraction of 8.0%. In the area of the European monetary union, economic activity fell by 5.1% and in Germany as the biggest economy in the Euro area, the GDP declined by 6.3% in the same period (see OECD, 2010b). The severe economic contraction forced many governments to take appropriate countermeasures, where retrospectively discretionary fiscal policies turned out to be a central tool to counteract the recession. In fact, the U.S. administration enacted economic stimulus packages in the years 2008 and 2009 that accounted for 5.6% of the GDP in 2008. For Japan and Germany, the sizes of the economic recovery plans were slightly lower but with 4.7% for Japan and 3.2% for Germany still remarkable (see OECD, 2010a).

Stabilization policies that aim at alleviating the effects of economic downturns have been the focus of a passionate decades-long dispute in macroeconomics that yet remains to be resolved. For a long time, the central question of this debate had been whether stabilization policies are an effective tool to smooth business cycles. The endogenous growth theory and its implication that any type of shock - be it temporary or permanent, real or nominal - can have permanent effects in the long run opened a new perspective: the link between short-term volatility and long-term growth. Inspired by this new perspective, a strand of the subsequent growth literature dealt with the question of whether stabilization policies will reduce or enhance long-term growth. A drawback of a large part of this literature is, however, that it has paid less attention to incorporating a concrete stabilization policy to check

whether the policy itself introduces implications for long-term growth. Instead of incorporating policies in the analysis, conclusions regarding the connection between stabilization policies and long-term growth have been solely derived from considering the link between short-term volatility and long-term growth. And in the sparse attempts that have explicitly accounted for stabilization policies, the explanation of the direction of possible long-term effects of stabilization policies has focused on either the modeling approach of endogenous technological change or the source of shocks driving the short-term volatility.

The concern of this paper is the important, but largely neglected, question whether the design of fiscal stabilization policies matters for the long-term effects of the policies. We use a closed agent-based macroeconomic model that generates endogenous business cycles to show that alternative fiscal policies can have different implications for long-term growth. Therefore, we run policy experiments in which three distinct fiscal policy measures are applied to mitigate the amplitude of the business cycle. The first policy provides consumption subsidies to households and the two other policies provide investment subsidies to firms. The difference between the investment subsidies is that the one policy subsidizes any investment in the physical capital stock and the other only those that flow in the most up-to-date technology. We can show that all policies are equally effective in smoothing business cycles but they substantially differ in their implications for long-term growth. In particular, the technology subsidy is associated with a strong positive effect on long-term growth while the consumption subsidy leads only to a weak positive effect. And for the investment subsidy, even a negative effect on the growth rate can be observed.

The policies analyzed in the experiments are stylized instances of policies that have actually been used by the U.S. government during the crisis. In the Economic Stimulus Act of 2008, the U.S. administration of President George W. Bush put together a stabilizing program that consisted of basically three main packages.¹ The largest package contained a \$100 billion tax rebate program for households. First estimates show that these tax rebates led to a stimulus of aggregate demand of 0.5 to 1.0% in the second quarter of 2008 and 0.16 to 1.81% in the third quarter of 2008 (see Broda and Parker, 2012). The other two packages contained business provisions that aimed at encouraging investments by increased limits on expensing investment costs and accelerated depreciation for some investments. According to estimations of the U.S. Congress, the investment enhancing policy reduced the tax revenue by \$51 billion in fiscal 2008 and 2009. Since the claims for depreciation were only anticipated, revenues have risen by \$43.5 billion in the subsequent years; but the net effect might still be \$7.5 billion. The American Recovery and Reinvestment Act of 2009 was signed into law by President Barack Obama as a follow up program of the Economic Stimulus Act. This package had a total size of \$900 billion and provided also tax cuts (\$275 billion) and increased existing programs. But in contrast to its predecessor, some of the measures contained in the American Recovery and Reinvestment Act had a strong focus on encouraging the technological advance of the U.S. economy.² Besides expending \$15 billion directly for scientific facilities and research, it provided over \$30 billion for investments in renewable energy and smart grid power networks as well as \$7 billion for expanding broadband internet access. This government money was designated to flow to both the private sector

¹See, e.g., <http://www.taxpolicycenter.org/briefing-book/background/stimulus/2008.cfm> (accessed on March, 29th, 2014).

²See, e.g., <http://www.recovery.gov/Pages/default.aspx> (accessed on March, 29th, 2014)

and directly to federal, state, and local government.

The importance of discretionary fiscal policies during the economic crisis does not correspond with the role that fiscal policy has recently played in contemporary macroeconomics. Going back in economic history, fiscal policy had been the central macroeconomic tool in the aftermath of the *Great Depression* and the following era of Keynesian macroeconomics (see Blanchard et al., 2010). But over the decades, the focus has been moving from fiscal to monetary policy and in the past two decades fiscal policy has taken clearly a backseat (see, e.g., Eichenbaum, 1997). The reasons for the declining importance of fiscal policy are manifold. One is the general skepticism regarding the effectiveness of fiscal policy as stressed by the New Classical school (see, e.g., Lucas and Sargent, 1979). A second reason might be problems of time lags in detecting recessions and the implementation of policies. But also issues related to the political economy might play a role. A third possible explanation is related to the *Great Moderation*, which is the empirically observed phenomenon of a substantial reduction in the volatility of U.S. business cycle fluctuations starting in the mid-1980s (Blanchard and Simon, 2001; Stock and Watson, 2003). Some studies such as Summers (2005) have shown that an improved monetary policy can explain the emergence of the moderation. But if there is already an effective policy to stabilize the business cycle, then there is no need for another policy instrument such as fiscal policies. The question remains, however, why governments have used fiscal policies so extensively during the crisis. Blanchard et al. (2010) argue that monetary policy, including quantitative easing and credit, had largely reached the limits with the result that policymakers had little choice but to rely on fiscal policy. Furthermore, fiscal stimulus measures had been more accepted by policymakers even before the crises and had been used in many instances, not only as a response to severe shocks.

Until the 1980s, short-term fluctuations and long-term economic growth had been considered by most mainstream macroeconomists as two coexisting and independent phenomena. As a consequence, a major divide had emerged in macroeconomic theory. On the one side, business cycle theorists had considered long-term growth as an exogenous trend and analyzed the cyclical component by typically using Keynesian macroeconomic models. On the other side, growth theorists had typically used Neoclassical growth models to analyze the trend component, where short-term shocks have no impact on the long-term growth rate of the economy (see, e.g., Gaggli and Steindl, 2008; Martin and Rogers, 2000). Stabilization policies that aim at smoothing the business cycles had then been analyzed in the context of short-term models neglecting any possible effect on the long-term growth rate. This traditional dichotomy eroded when Nelson and Plosser (1982) found empirical evidence that long historical time series data for the U.S. could be characterized by non-stationary processes that have no tendency to return to a deterministic path. When decomposing the time series in a secular and a cyclical component, shocks to the secular component would substantially contribute to the variation in observed output. As a consequence, Nelson and Plosser (1982) questioned the general separation of business cycle and growth theory.

Real Business Cycle (RBC) models were the first models that incorporated business cycles and long-term growth in a unified framework. Classic RBC models such as Kydland and Prescott (1982) amended the neoclassical growth model by stochastic technological growth. In RBC models, the economy is characterized by a general equilibrium with rational expectations and fully flexible prices, in which households maximize life-time utility and price-taking firms maximize profits. Volatility is in-

troduced by real shocks to the technology, where the optimal response of firms and households causes business cycle fluctuations. Long-term growth is determined by a long-term steady state path so that stabilization policies have typically no implications in the long run. But in the short run, fiscal policies can have positive effects. In a literature survey, Hebous (2011) describes the short-term effect of a fiscal expansion in a typical RBC model as follows: the rational household realizes that government spending is financed by future taxes. This causes a negative wealth effect as the present value of the household tax liability increases. As a result, consumption declines whereas interest rate, saving and labor supply increase. The increasing labor supply in turn causes real wages to fall whereas investment and output increase. In this case, fiscal policy can stabilize the economy in the short run.

Forward-looking, microfounded New Keynesian models are the second important branch in contemporary macroeconomics. Early New Keynesian models aimed at describing the dynamical behavior of output, inflation, and nominal interest rates and were mostly focused on monetary policies (see, e.g., Mankiw and Romer, 1991). Recent New Keynesian models adapted many features of RBC models but differ in their explicit consideration of nominal rigidities such as price and wage stickiness and the assumption of monopolistic competition on markets for intermediate goods (see, e.g., Ireland, 2004). Growth is exogenous by construction with the result that in a New Keynesian setup stabilization policies have no implications for the long-term growth (compare Gaggli and Steindl, 2008). Thus, predictions of these models regarding possible long-term effects of stabilization policies are in line with that of RBC models. Regarding the short-term effect, Hebous (2011) points out that the predictions of typical New Keynesian models are also similar to those of RBC models, i.e. an increase in output and a decrease in consumption. But differences emerge at the labor market; the rising output increases labor demand, which offsets the increased labor supply due to the negative wealth effect.

In the last two decades, the borders between RBC and New Keynesian models have been blurred and to some extent even disappeared. This softening of the methodological stance has been accompanied by a general convergence of the New Classical and the New Keynesian school, which is also associated with a reduction of the fundamental disagreement among macroeconomists of the two different schools. This process of convergence has been discussed in the literature under the term *New Neoclassical synthesis* (see, e.g., Goodfriend and King, 1997). In fact, many recent macroeconomic models combine elements of both approaches. The major workhorse in mainstream macroeconomics are models that feature the structure of RBC models and inherited nominal rigidities from New Keynesian models (see, e.g., Woodford, 2009).

In any case, the line of research that has applied models with RBC and/or New Keynesian features is basically interested in replicating business cycles and analyzing transient effects of shocks on macroeconomic aggregates. The determination of long-run growth is not the question of this research *per se* (Gaggli and Steindl, 2008). Since the steady state growth is exogenous by construction, models of both types cannot account for a causal relationship between short-term volatility and long-term growth as evidenced by Nelson and Plosser (1982).

The endogenous growth literature has tried to fill this gap. The key assumption and main difference to the RBC and New Keynesian literature is that in endogenous growth models technological change is not determined exogenously but endogenously. The process of technological change, which is the main driver of

long-term growth, has many determinants, including investments in human capital and research and development. Some of these determinants are influenced by the volatility of the business cycle, which provides a connection between short-term fluctuations and long-term growth. In that sense, endogenous technological progress acts as a propagation mechanism for shocks that have only transitory effects in New Keynesian and RBC frameworks (Stadler, 1990).

The endogenous growth literature provides an ambiguous answer to the question of the relationship between (the smoothing of) cyclical fluctuations and long-term growth. In this context, two contrasting explanatory paradigms can be identified, reflecting two different approaches for the modeling of endogenous technological change: the one following Schumpeter's concept of creative destruction and the other based on the learning-by-doing hypothesis (see Priesmeier and Stähler, 2011).

In models following the creative destruction hypothesis, one can typically find a positive link between short-term fluctuations and long-term growth. This positive effect emerges as recessions have a positive effect on the long-term productivity level of the economy. There are basically two explanations for this positive relation. The first describes a cleansing effect of recessions (Caballero and Hammour, 1994), through which unproductive firms that lack competitiveness are driven out of the market. As a consequence, the overall productivity of the economy will be higher when the economy recovers. The second explanation, used by e.g. Aghion and Saint-Paul (1998), stresses the importance of procyclical opportunity costs for productivity-enhancing activities. According to Saint-Paul (1997), activities such as research and development, training, and implementation of new technologies are costly in terms of forgone current production. This is because these activities tie up production capacities that are not available for production. Therefore, in a recession when output is currently low, the cost of such activities is low relative to their benefit, which includes increased production in the future when the economy is back to an expansionary phase. An important aspect of this mechanism is, as argued by Saint-Paul (1997), the intertemporal substitution of productivity-enhancing activities for direct production activities, which are postponed to better times.

In any case, the assumption of creative destruction being the main driver of endogenous technological change implies a trade-off between short-term volatility reduction and long-term growth. If the policy reduces the business cycle and therefore prevents the economy to fall into recession, then it will also suppress the cleansing mechanism or, respectively, the reduction of opportunity costs. As a result, the speed of technological change will eventually fall. This implies a conflict of goals so that a government must sacrifice long-term growth for achieving short-term stability.

Aghion et al. (2005) show that the opportunity cost argument is only valid if credit markets are perfect. If credit markets are sufficiently imperfect, then productivity-enhancing investments become procyclical and a reduction of the volatility would lead to higher growth. In this scenario, the goals of short-term stabilization and long-term growth are not conflicting. This finding is consistent with the results one typically obtains when considering the alternative explanatory paradigm for endogenous technological change, the learning-by-doing hypothesis. In models of this type as e.g. Stadler (1990), Martin and Rogers (1997, 2000), the propagation mechanism is assumed to emerge through an endogenous formation of human capital. Stadler (1990) describes the learning process as a by-product of production in which workers build up skills and experiences during their employment. Since labor can move freely between firms, the generated skills become an externality and constitute to a common stock of technical knowledge. Periods during a negative

output shock, when output and employment are low, are forgone opportunities for learning-by-doing and have a negative effect on the accumulation of human capital. If, as Martin and Rogers (2000) argue, the employment is increasing and concave in the business cycle disturbance, the forgone learning cannot be fully regained over the next upswing. Then, a transitory shock translates in a permanent effect on the long-term growth path of the economy. In this case, a stabilization policy that counteracts a negative shock will have an enhancing effect on long-term growth.

But the picture is also not unambiguous for models based on the learning-by-doing hypothesis. Blackburn (1999), for example, shows that it depends on the concrete specification of the human capital accumulation function, i.e. the technology underlying the learning process, to determine whether growth and volatility are positively related. And Blackburn and Pelloni (2004) emphasize the source of the fluctuation. Their analysis of a monetary growth model with nominal rigidities and learning-by-doing predicts that the relationship between output growth and output volatility may be positive or negative according to whether real or nominal shocks predominate.

The focus of most endogenous growth models has been on the relation of short-term volatility on long-term growth, from which possible effects of stabilization policies are derived as a corollary. This, however, does not include issues of formulation and evaluation of stabilization policies, a point that has to some extent been neglected in the literature. Blackburn (1999) and Blackburn and Pelloni (2005) consider monetary stabilization policies governed by feedback rules. While the former finds a negative effect on long-term growth, the latter find that the monetary stabilization policy may work either for or against the promotion of long-term growth depending on the source of the fluctuations. Martin and Rogers (1997) develop a model in which learning-by-doing is at the origin of growth and analyze the effects of a fiscal stabilization policy that subsidizes labor during bad periods and taxes in good times. They find that in many configurations of disturbances and model parameters, the countercyclical tax policy can have positive effects on long-term growth by minimizing the adverse effects that recessions have on learning-by-doing. These examples illustrate that mostly structural aspects have been emphasized in the few investigations that incorporate a concrete stabilization policy. These structural aspects include the specification of the learning function (Blackburn, 1999), the nature of the shocks (Blackburn and Pelloni, 2005), and structural parameters controlling the severity of shocks, their likelihood to occur, and the speed of learning (Martin and Rogers, 1997). But no emphasis has been put on investigating the question whether different (fiscal) policies, which all aim at stabilizing the business cycle can have different implications for the long-term growth path.

This paper aims at addressing this question by means of an agent-based policy analysis. The model used for the policy analysis is an extended version of the agent-based macro model Eurace@Unibi (see Dawid et al., 2012b). We opt for a closed agent-based macro model because of some important generic properties of the agent-based approach. Especially the explicit representation of heterogeneous interacting agents makes an agent-based model to an appropriate tool for analyzing the long-term effects of fiscal stabilization policies. This modeling approach can explicitly capture the emergent dynamics of skills, productivity and wages that arise at the micro level and that are important drivers of the evolution of aggregate variables at the macro level. An explicit modeling of feedback loops between the micro and macro level will be particularly important if the considered policies influence the emerging dynamics at the micro level in different ways and, therefore, lead to

different dynamics at the aggregate level.

In the model, heterogeneous households and firms interact on labor and goods market. Productivity of firms is determined by relating specific skills of workers and the productivity of the capital stock in a complementary way. There is a capital goods market at which vertically differentiated vintages of the capital good are offered. The choice in which vintage a firm invests is explicitly modeled as part of the investment decision. The endogenous vintage choice allows incorporating an aspect that has yet received less attention in the integrated business cycles and growth literature, the process of technological diffusion. While technological shocks are the main source of fluctuations in several models of the RBC, New Keynesian and endogenous growth literature, Blanchard (2008) argues that technological progress is a smooth process as it is about the diffusion and implementation of new ideas. And Comin (2009) shows in a theoretical framework that the diffusion process amplifies the business cycle and that temporary fluctuations in the intensity of adoption will have persistent effects on the productivity. Our model accounts for a possible propagation mechanism through technological diffusion and can therefore assess possible implications of this transmission channel for stabilization policies.

Besides the diffusion of technologies, also the accumulation of human capital within firms and the allocation of human capital among firms is modeled in an explicit microfounded way. The productivity of workers is determined through learning-by-doing; in that sense the model shares a common feature with the strand of learning-by-doing models in the endogenous growth literature. However, the learning takes place at the individual level, i.e. single workers build up skills for the technology they are currently using at the workplace. Since workers can switch jobs via an explicitly modeled labor market, the knowledge transfer between firms in the form of spillovers is endogenized and takes place at the disaggregated firm level. This is in contrast to the assumption of endogenous growth models that assume perfectly externalized knowledge spillovers (see, e.g., Stadler, 1990).

In most mainstream macroeconomic models, exogenous stochastic shocks are the source of short-term fluctuations, where these disturbances hit the economic system when the economy is either in equilibrium or at the way back to equilibrium. The fact that these models require shocks in order to introduce business cycles has been criticized by e.g. Dosi et al. (2006). In contrast, the model presented in this paper generates endogenous business cycles that emerge through a complex interplay of investment, pricing and production strategies as well as financing opportunities of heterogeneous and boundedly rational firms. These endogenous business cycles make the analysis of stabilization policies independent from the introduction of exogenous disturbances.

The model exhibits a government that runs automatic stabilizers in the form of income and profit taxes as well as unemployment benefits. Furthermore, the government installs and finances the three discretionary stabilization policies analyzed in the policy experiments. In order to abstract from time lags and politically economic considerations, we model the policies as quasi feedback rules so that stabilization policies are applied without time lags as soon as a downturn has been detected. The government is allowed to run deficits with the consequence that the government can accumulate public debts. The tax rates are assumed to be fixed and set such that without the implementation of a discretionary policy the budget is intertemporally balanced. This setting provides the opportunity to investigate the implications of the different policies for public debts, which has recently become a relevant concern due to the current government debt crisis in Europe.

In general, there is a growing literature on agent-based macroeconomic modeling. In the last ten years, a number of closed macroeconomic models using an agent-based approach have been developed (see, e.g., Ashraf et al., 2011; Dawid et al., 2012a; Delli Gatti et al., 2010; Dosi et al., 2006; Gintis, 2007; Wolf et al., 2013). Several of these agent-based macroeconomic models show the importance of the approach for economic policy evaluation. Monetary policies are addressed in Ashraf et al. (2012) or Arifovic et al. (2013), whereas regulatory issues relating to credit and financial markets are analyzed by Delli Gatti et al. (2010) or Ashraf et al. (2011) within agent-based macroeconomic models.

Previous versions of the model presented in this paper have been used for policy analyses in the context of regional convergence (see, e.g., Dawid et al., 2012a, 2014). Dawid et al. (2012a) analyze the effect of labor market integration policies on the convergence of regions. Dawid et al. (2014) study the effectiveness of cohesion policies subject to the spatial integration of labor markets.³

Dosi et al. (2010) have carried out an analysis similar to ours in which they examine short- and long-term effects of different policies within an agent-based macro model with endogenous business cycles. In their analysis, they consider two policy regimes. The first is a Keynesian policy that consists of an automatically stabilizing fiscal policy in the form of taxes on wages and profits as well as unemployment benefits; the second is a Schumpeterian policy that can change several fundamentals of the innovation process thereby facilitating technological change. They show that if the Keynesian policy is switched off, the average growth is much lower and the short-term volatility is higher. In that sense, Dosi et al. (2010) find a positive link between fiscal stabilization policy and long-term growth. However, the focus of their study is not the policy design of fiscal stabilization policies but the interaction of the Keynesian policy with the Schumpeterian policy. They find a complementary relation between the policies so that without a Keynesian policy the effect of the Schumpeterian policy is almost zero. But if the Keynesian policy is switched on, then the Schumpeterian policy has positive effects on long-term growth.

The paper is organized as follows: Section 3.2 lays out the model. In Section 3.3 we show some characteristics of the endogenous business cycle and relate them to empirically observed stylized facts. Section 3.4 contains an extensive policy analysis of the policy question raised above. Section 3.5 provides a detailed sensitivity analysis of the model regarding its parametrization as well as robustness checks for the policy experiments. Finally, Section 3.6 concludes.

3.2 The Model

3.2.1 The Overall Structure

The model describes a market economy in which heterogeneous agents interact on different markets. The agents populating the economy are households, firms, where we distinguish consumption and capital goods producing firms, and banks. Additionally, there is a central bank and a government that collects taxes and finances social benefits.

The focus of our analysis is on the real sector of the economy including a consumption goods market, a capital goods market and a labor market. At the market for consumption goods, firms produce a homogeneous consumption good that is sold at a central market place called outlet mall. Households are consumers and

³This paper can be found in Chapter 2 of this thesis.

they purchase the consumption good when visiting the outlet mall several times per month.

For the production of the consumption good, firms require labor and capital as inputs which they can purchase at the corresponding factor markets. A monopolistic capital goods firm produces vertically differentiated capital goods and offers several vintages of the capital good at a time. The vintages differ with respect to productivity. From time to time, the capital goods firm carries out a successful innovation and introduces a new vintage with an improved quality onto the market. Thus, technological change is embodied as innovations diffuse into the economy through capital goods investments.

The labor market is populated with workers that have either high or low general skills as human capital endowment. Moreover, workers build up technology specific skills on the job. A crucial assumption is hereby that the specific skills of workers and the productivity of machines are linked in a complementary way. This implies that better technologies can only be used efficiently when workers have already acquired sufficient specific skills. Firms adjust the workforce according to their labor demand where the labor market interactions are modeled as a search and matching process.

Households earn a labor income or, if unemployed, they receive unemployment benefits from the government. Moreover, since households are shareholders of firms, they receive dividends. Based on the monthly income and driven by precautionary motives, households determine once a month how much of the income they will spend for consumption during the month.

Consumption goods firms retain parts their profits as a cash reserve or for financing capital investments. As an alternative financing source, firms can obtain external financing at a credit market. Credits are provided by commercial banks which collect deposits of firms and households. Whether a loan is accepted and how much interests the firm has to pay depends on its financial standing. However, the ability to provide credits is limited by regulations regarding capital requirements and cash reserves.

Firms that are not able to pay their financial commitments declare illiquidity. If debts exceed wealth at the end of the production cycle, a firm has to declare insolvency. In both cases, a bankrupt firm is liquidated after stopping production and dismissing all employees. On the other side, new firms enter the market incidentally starting from scratch only endowed with an initial stock of cash that is provided by a venture capitalist.

The financial sector is completed by a financial market at which agents can trade shares of a single asset. This asset is an index bond that contains all firms and banks of the economy. The total sum of dividends paid out by all firms is distributed among households according to the number of shares a household owns. The central bank provides standing facilities for the banks at a given base rate, pays interest on banks' overnight deposits and might provide fiat money to the government.

Finally, there is a statistical office (Eurostat) that collects data from all individual agents in the economy and generates aggregate indicators according to standard procedures. These indicators are distributed to the agents in the economy which might use them as input for their decision rules.

Agent actions can be time-driven or event-based, where the former can follow either subjective or objective time schedules. Furthermore, the economic activities follow a hierarchy of time-scales: yearly, monthly, weekly and daily activities, all taking place following calendar-time or subjective agent-time. Agents are activated asynchronously according to their subjective time schedules that are anchored on an

individual activation day. These activation days are uniformly randomly distributed among the agents at the start of the simulation, but may change endogenously (e.g., when a household gets re-employed, its subjective month gets synchronized with the activation day of its employer due to wage payments). This modeling approach is supposed to capture the decentralized and typically asynchronous nature of decision-making processes and activities of economic agents.

In the following subsections, we describe main aspects of the model in more detail, where we focus on the innovations introduced to the consumption and capital goods sector of the Eurace@Unibi model. Furthermore, we describe aspects of the model, which are crucial for the understanding of the results discussed below. A detailed description of the other parts of the model such as the financial and credit market is provided in Dawid et al. (2012b).

3.2.2 Decision-Making and Expectation Formation

While agents in a typical dynamic equilibrium model are endowed with rational expectations and perfect information on their environment, agent based models are characterized by bounded rationality. This requires the formulation of explicit rules describing how agents build expectations and how they take their decisions based on the available information. In our model, this is captured by modeling the decision-making of agents using a rule-based approach; rule-based means that agents of the same type have an identical set of behavioral rules, each specifically designed for solving a particular decision problem. The design of the decision rules is based on a systematic attempt to incorporate empirically observable behavior documented in the relevant literature. Concerning households, this means that the saving rule and purchasing choice are described by using models from the marketing literature with strong empirical support. With respect to firm behavior, we follow the *Management Science approach*, which aims at implementing decision rules and heuristics that match standard procedures of real world firms as described in the corresponding management literature. A more extensive discussion of the Management Science approach can be found in Dawid and Harting (2012).⁴

In general, the decision rules are parametrized, where different values of parameters can lead to different outcomes of a particular rule. Besides exogenous model parameters, those parameters can either be agent specific variables or aggregated (macro) variables provided by the statistical office Eurostat.

Current values of some variables are ex ante unknown such that agents have to form expectations. For most of them, especially for aggregated variables, the agents use adaptive expectations, i.e. the expected value depends on observed values in the past. A special case is, however, the estimation of the uncertain demand. In this context, the price sensitivity of households in the consumption choice is important information when planning the production and investment. But it is not possible to estimate the price sensitivity from observable information. In order to gather reliable information, firms carry out market research by conducting simulated purchase surveys (see Section 3.2.4.1).

Expectations on the future value of certain variables are not only important as parameters for the decision rules. Some of them are also used as objective variables based on which a decision is eventually taken. Therefore, agents apply procedures to determine estimated values for those variables conditioned on different possible realizations of the decision. Instances of more sophisticated procedures are estima-

⁴This paper can be found in Chapter 1 of this thesis.

tions of profits of consumption goods firms conditioned on the price as it is used for the pricing (see Section 3.2.4.2) or cash flow estimations associated with different investment strategies as used in the investment planning (see Section 3.2.4.3).

3.2.3 Skill Dynamics

We assume that workers are characterized by two dimensions of human capital endowments. The first dimension is the general skill level and can be interpreted as the formal qualification and those abilities that a worker has obtained during schooling and professional education. There are two skill groups $b_h^{gen} \in \{1,2\}$ with b_h^{gen} referring to the general skill level of worker h . The two groups represent low and high levels of general skills, where workers from skill group 1 belong to the low-skill group and those with skill level 2 to the high-skill group.

Specific skills are the second dimension of human capital. They are technology related and are measured in terms of productivity. They can be interpreted as competences and the experience a worker has collected while working with a certain production technology. The underlying assumption of learning-by-doing is thereby supported by empirical evidences. Bahk and Gort (1993), e.g., found a significant effect of learning-by-doing on output of 15 industries, where the learning appeared to be uniquely related to embodied technological change of physical capital.

The learning process and hence the speed of acquiring specific skills is assumed to be depending on the general skill level of the worker. Suppose the machines used by h 's employer i at time t have an average productivity of A_{it} , then the specific skills of worker h evolve according to

$$b_{ht+1} = b_{ht} + \chi(b_h^{gen}) \cdot \max[0, A_{it} - b_{ht}]. \quad (3.1)$$

The function χ is thereby increasing in b^{gen} . Note that we assume that the generation of new technologies is a cumulative process. This implies that specific skills are transferable between vintages, even from old to new technologies.

Furthermore, we assume that general skills are observable by firms in the hiring process while specific skills are not. But specific skills become observable ex post during the production process.

3.2.4 The Consumption Goods Firm

For the production of the consumption good, firms use labor and physical capital as input factors. The capital stock of a firm is composed of different vintages of the capital good. It depreciates over time and increases through investments such that the accumulation of capital of a vintage v follows the law of motion

$$K_{it}^v = (1 - \delta) \cdot K_{it-1}^v + I_{it}^v. \quad (3.2)$$

The parameter δ is the depreciation rate and I_{it}^v is the investment in vintage v . Technology is embodied in the capital stock and characterized by vintage specific productivity levels A^v .

The production technology is represented by a Leontief production function such that labor and capital are used in a complementary way. Moreover, there is a complementarity between the productivity of a vintage v and the average specific skills level B_{it} of the workforce of the firm. This implies that a vintage cannot be used at its full productivity as long as the workers have not acquired a sufficient level of specific skills.

Given the capital stock and the number of workers L_{it} , the produced output can be computed according to the production function

$$Q_{it} = \sum_{v=1}^{V_t} \min \left[K_{it}^v, \max \left[0, L_{it} - \sum_{k=v+1}^{V_t} K_{it}^k \right] \right] \cdot \min [A^v, B_{it}]. \quad (3.3)$$

The output Q_{it} is sent to the mall in which it is added to the inventory stock and supplied to households.

The demand for the product of a firm is stochastic. In the Management science literature there are standard heuristics for production planning problems facing stochastic demand. A simple heuristic prescribes to generate an estimation of the distribution of demand and to supply a quantity that is sufficient to fully serve the emerging demand at a probability χ^S . The converse probability $1 - \chi^S$ is then the stock-out probability (which is influenced by stock-out costs, inventory costs and the risk attitude of the firm, see, e.g., Silver et al., 1998). The planned output is then the difference of that target supply and the current inventory stock at the mall (see Section 3.2.4.2).

The estimated demand depends on the price that is set before the firm decides the production plan. It is determined with a procedure that is described in Section 3.2.4.1. After the determination of the target output, the firm determines the labor demand and the financial needs. The production plan might induce the need to hire new labor or to obtain additional credits, where there is the possibility that firms are rationed on the labor or credit market. In these cases, the output and prices are both adjusted accordingly.

Disconnected from the production planning is the capital investment decision, which is taken before the firm enters the production planning (see Section 3.2.4.3). In the financial planning, however, both the production plan and the investment plan are considered and, in case of credit rationing, the investment is revised and adjusted first.

3.2.4.1 Demand Estimation

The price and investment choice are core decisions of the consumption goods firm predetermining most of the activities following in the production chain. Because of their operative and strategic importance, these decisions are based on sophisticated procedures, which judge the available options by predicting possible effects on the firm's performance. For both decisions, an important ingredient is an accurate estimation of the demand. However, the demand for the product of a firm is governed not only by its own price but also by other factors which cannot be controlled by the firm itself. Those factors are, for example, the development of the total market, strategies of competitors and consumer specific attributes.

In an elaborate estimation procedure, firms try to find a closed form expression for the demand that translates observed or unobserved but estimated determinants of the demand into an expected value. This expected demand can be used in the production planning. The derivation of this demand function is decomposed in two steps. The first step describes an estimation of the development of the consumption goods market represented by the growth of the market size. The market size is given by the overall budget of households disposed for consumption. We assume that firms can ex post observe the aggregated consumption budget, where they use previous realizations to predict the market development by estimating an expected growth rate \hat{g} .

Let MS_{t-1} be the observed market size in the previous period and \hat{g}_{it} the average monthly growth rate of the market between period $t - T^S$ and $t - 1$; then, the firm assumes that the market size for the current period t is

$$\hat{M}S_{it} = MS_{t-1} \cdot (1 + \hat{g}_{it}). \quad (3.4)$$

In the decision process for capital investments, the firm requires estimates of the market sizes for periods further ahead, i.e. for $t + \tau$ with $\tau > 0$. In this case, the firm adjusts the expected growth rate by assuming that the more farsighted the estimation is, the more the growth rate approaches its long-term average \hat{g}^L . With $\hat{g}_{it+\tau}$ being the corresponding expected growth rate for period $t + \tau$, the expected market size for this period is computed according to

$$\hat{M}S_{it+\tau} = \hat{M}S_{it+\tau-1} \cdot (1 + \hat{g}_{it+\tau}). \quad (3.5)$$

The second step of the demand estimation describes which market share the firm can expect to achieve. Since sales of the firm are driven by the consumer's choice of households, this procedure must try to incorporate those factors influencing households' purchasing decision. We assume that the estimation follows a procedure that is proposed in Train (2009). Train (2009) describes a discrete choice model in which a household indexed h can choose one good from a set of available goods \mathbf{J} , where good j is selected with a probability $prob_{hj}$.

The average choice probability $prob_j$ for the product of the firm is used as a proxy for its market share. In order to find a closed form expression for the choice probabilities, the firm assumes that consuming good j denotes household h a utility U_{hj} which is represented by a utility function

$$U_{hj} = \gamma \log(p_j) + \epsilon_{hj}. \quad (3.6)$$

The variable ϵ_{hj} is independently, identically distributed extreme value and γ is an unknown parameter. The intuition of this utility model is that the firm knows that the price p_j of the good is an important factor for the consumer's choice. There may also be others, either product or household specific factors but those are unknown and treated by the firm as random.

In this case it can be shown that the probability to choose product j over the other products is a multinomial logit probability given by

$$prob_{hj} = \frac{\exp(\gamma \log(p_j))}{\sum_{\forall k \in \mathbf{J}} \exp(\gamma \log(p_k))}. \quad (3.7)$$

The parameter γ is the intensity of choice that indicates how sensitive the demand reacts on price changes. However, this parameter is a consumer specific variable that cannot be easily estimated with data observed at the market. Thus, in order to estimate γ , the firm carries out simulated purchase surveys as described in Nagle and Hogan (2006). We assume that the firm draws a random sample of consumers and present them a set of products at differing prices. The interviewed households are asked to decide for one of the presented goods based on the same considerations as if they would do their normal shopping.

Based on the reported decisions in combination with the prices of the presented goods and the assumed model for the choice probability (Expression 3.7), the firm can estimate the parameter γ by maximizing the log-likelihood function

$$LL(\gamma) = \sum_{h'=1}^{n^S} \log(prob_{h'}(\gamma)) \quad (3.8)$$

with respect to γ . In the log-likelihood function, $prob_{h'}(\gamma)$ denotes the probability of the observed outcome for the decision of household h' and n^S is the sample size that has to be sufficiently large. The maximization problem is numerically solved by applying the Newton-Raphson algorithm as proposed by Train (2009).

The estimator $\hat{\gamma}$, which is the best fitting value for γ , is then used to estimate the market share in period $t + \tau$ associated with price \tilde{p} . Suppose $\hat{\mathbf{p}}_{-it+\tau}$ is the vector of expected prices of all competitors in period $t + \tau$, then the estimated market share is

$$\hat{s}(\tilde{p}, \hat{\mathbf{p}}_{-it+\tau}) = \frac{\exp(\hat{\gamma} \log(\tilde{p}))}{\exp(\hat{\gamma} \log(\tilde{p})) + \sum_{k \in \hat{\mathbf{p}}_{-it+\tau}} \exp(\hat{\gamma} \log(p_{kt+\tau}))}. \quad (3.9)$$

For the prices of the competitors, we basically assume the same expectation formation as for the market growth. There are adaptive expectations so that the price of an individual competitor k is expected to change by the average monthly inflation rate π observed over the last T^S months. However, the more a considered period is ahead, the more the expected inflation rate approaches its long-term average.

After both steps, i.e. the determination of the expected market size as step one and the estimation of the market share as step two, the firm combines the results of the two steps to determine a functional form for the expected demand in $t + \tau$, which is

$$\hat{D}_{it+\tau} = \frac{1}{p_{it+\tau}} \cdot MS_{it+\tau} \cdot \hat{s}(p_{it+\tau}, \hat{\mathbf{p}}_{-it+\tau}). \quad (3.10)$$

Note that the market size MS is measured in monetary units; in order to express the demand in real terms, the product of market share and market size must be divided by price $p_{it+\tau}$.

3.2.4.2 Pricing and Production Planning

The price setting of consumption goods firms is based on an elaborate analysis of potential profits. Therefore, the firm defines a set of candidate prices $\tilde{\mathbf{P}}$ that is drawn from an interval around the price p_{it-1} charged in the last month. The firm estimates revenues and costs for the upcoming production cycle associated with each candidate price and selects that price with the highest potential profits.

The decision regarding prices and output levels are shortsighted and disconnected from the more farsighted investment decision (see Section 3.2.4.3). For this reason, the production capacity is not adjusted to lower prices even if they yield higher expected profits. Thus, when estimating the revenues and costs, the firm has to take into account that the production quantity is constraint by the capital stock. The maximum output that can be produced with the capital stock including the pending investments of the current period is

$$\bar{Q}_{it} = \sum_{v=1}^V K_{it}^v \cdot \min[A^v, B_{it-1}]. \quad (3.11)$$

The expected revenues associated with a candidate price \tilde{p} are the proceeds of selling a certain quantity at price \tilde{p} . Sales are basically determined by the demand \hat{D}_{it} that depends on the firm's own price \tilde{p} and the prices of the firm's competitors $\hat{\mathbf{p}}_{-it}$. Since the firm cannot sell more goods than available, sales are limited by the sum of the inventory stock S_{it-1} left over from the previous period and the feasible output \bar{Q}_{it} . The expected revenue is then

$$\hat{R}_{it}(\tilde{p}) = \min \left[\hat{D}_{it}(\tilde{p}, \hat{\mathbf{p}}_{-it}), S_{it-1} + \bar{Q}_{it} \right] \cdot \tilde{p}. \quad (3.12)$$

The expected production quantity associated with price \tilde{p} is given by

$$\hat{Q}_{it}(\tilde{p}) = \min \left[\bar{Q}_{it}, \hat{D}_{it}(\tilde{p}, \hat{\mathbf{p}}_{-it}) + \hat{\Psi}_{it} - S_{it-1} \right]. \quad (3.13)$$

The variable $\hat{\Psi}$ yields an inventory buffer that depends on the expected volatility of the demand σ_D^2 and the accepted stock-out probability $1 - \chi^S$. Assuming a normally distributed demand, the buffer is determined according to

$$\hat{\Psi}_{it} = \hat{D}_{it}(\tilde{p}, \hat{\mathbf{p}}_{-it}) \cdot q_{\chi^S} \cdot \sqrt{\sigma_D^2}, \quad (3.14)$$

where q_{χ^S} is the χ^S -quantile of the normal distribution and σ_D^2 and χ^S are exogenous model parameters.

Since the investment costs are sunk and, therefore, fixed costs in the profit calculation, the only cost type that affects the price setting are labor costs. Suppose \hat{L}_{it} is the labor demand required to produce $\hat{Q}_{it}(\tilde{p})$ and w_{it-1}^{base} is the base wage offer (for a detailed description of the determination of wage offers see Section 3.2.6). The estimated average wage that the firm has to pay for its workforce would then be

$$\begin{aligned} \hat{w}_{it} = & \frac{\max \left[\hat{L}_{it} - L_{it-1}, 0 \right]}{\hat{L}_{it}} \cdot w_{it-1}^{base} \min[A_{it-1}, \hat{B}_{it-1}] + \\ & + \frac{\min \left[L_{it-1}, \hat{L}_{it} \right]}{\hat{L}_{it}} \cdot w_{it-1}. \end{aligned} \quad (3.15)$$

Expression 3.15 incorporates that the wage for additionally hired workers deviates from the average wage w_{it-1} of the incumbent workforce.

Altogether, we can write the expected profit associated with a candidate price \tilde{p} as

$$\hat{\Pi}(\tilde{p}) = \hat{R}_{it}(\tilde{p}) - \hat{L}_{it}(\tilde{p}) \cdot \hat{w}_{it}(\tilde{p}). \quad (3.16)$$

The firm chooses that price which yields the highest expected profit for the next month, i.e.

$$p_{it} = \arg \max_{\tilde{p} \in \tilde{\mathbf{P}}} \hat{\Pi}(\tilde{p}). \quad (3.17)$$

After completing the price setting, the firm can determine the planned production quantity and the input and financial needs to fulfill the desired production plan. The planned output is

$$\tilde{Q}_{it} = \min \left[\bar{Q}_{it}, \hat{D}_{it}(p_{it}, \hat{\mathbf{p}}_{-it}) + \Psi_{it} - S_{it-1} \right], \quad (3.18)$$

where \tilde{Q}_{it} is determined according to Expression 3.11.

For the determination of the labor demand, the firm draws on the labor productivity of the previous production cycle. Let Q_{it-1} be the actual production in $t-1$ and L_{it-1} the employed workforce to produce Q_{it-1} , hence, the labor demand in period t is given by

$$\tilde{L}_{it} = \tilde{Q}_{it} \cdot \frac{L_{it-1}}{Q_{it-1}}. \quad (3.19)$$

3.2.4.3 Investment Decision and Vintage Choice

It is the nature of investment projects to spend money with the expectation to gain over a longer term. Therefore, the investment decision of consumption goods firms is based on an appraisal of whether long-term capital investments are worth the funding of cash. That means the firm evaluates the investment options systematically by checking whether an investment is potentially profitable over a planning horizon rather than to decide based on a myopic consideration of output expansions in the current production period.

Firms can purchase different vintages of the capital good at the capital goods market that are distinguished by their embodied productivity and the market price. For this reason, the investment decision is not only to decide on the quantity but also in which vintage of the capital good the firm should invest.

We assume that the decision-making is a three step process. In the first step, the firm appraises the investment strategies and preselects the most profitable one. Given the required expenditures for the best strategy and the current financial situation, the firm checks in the second step whether it has to raise additional credits to finance the project. If external financing is needed, the firm assesses the impact on its financial stability. If it turns out that the investment risks the financial standing, then the project is abandoned.

The third step takes account of the fact that timing of investments can also matter. A capital investment is an opportunity that can either be executed today or postponed to a later date. But, due to its irreversibility, once it has been committed it cannot be recovered. In those cases, deferring can yield additional value because the economic environment can change in the meantime and so might the estimated value when reevaluating the project after the arrival of new information. If a project is postponed and later it turns out that the value has not changed or has even increased, the firm has still the opportunity to carry out the investment. But if it turns out to be a poor investment, the deferring strategy has preserved the firm to make possible losses. However, by waiting and not carrying out the investment immediately, the firm can also make losses in the form of foregone profits. The investment is finally executed if the forgone expected profits exceed the additional value of waiting.

In the following, we consider the steps pre-selection, financial impact, and optimal timing in more detail.

Preselection: A standard textbook method for evaluating investment projects is the net present value (NPV) technique. The net present value is defined as the sum of discounted expected cash flows over a planning horizon. Capital budgeting based on NPV techniques is also reported to be widely used by Chief Financial Officers (CFO) in their decision-making (see, e.g., Ryan and Ryan, 2002). Following the Management Science approach, we assume that this method is applied by consumption goods firms for pre-selecting the most profitable investment from the set of available strategies.

Suppose $I^{v'}$ is the investment project under consideration, where $I^{v'}$ denotes the amount that would be invested in vintage v' . For the sake of simplicity, firms assume that it is always worth keeping the capital stock constant over the considered planning period, where depreciated capital is replaced by capital of vintage v' . Then, the expected cash flow for a given future period $t + \tau$ is the inflowing revenue minus the outflowing labor costs and capital expenditures to reacquire the depreciated

capital. Formally, we can write

$$\hat{C}F_{it+\tau} = \hat{R}_{it+\tau} - \hat{w}_{it+\tau} \hat{L}_{it+\tau} - \hat{p}_{It+\tau}^{v'} \left(\sum_{v=1}^V \delta K_{it}^v + \delta I^{v'} \right). \quad (3.20)$$

For determining revenues, the firm needs an accurate estimation of possible sales. Sales are basically determined by the demand but at the same time sales are also limited by the amount of available goods. The available goods, in turn, are partially determined by the stock left over from the previous period. In order to account for these intertemporal links in the production planning of the foresighted investment evaluation, we distinguish two different types of demand expectations. First, we define the ex ante demand $\hat{D}_{it+\tau}$ as demand that the firm assumes to face at the beginning of a period $t + \tau$; this demand expectation is used for the determination of the notional output and price (see below). Its determination is described in Section 3.2.4.1. Second, we define the ex post demand $\hat{D}_{it+\tau}^P$. This demand expectation is the amount of goods that is subtracted as notional sales from the calculated inventory at the end of planning period $t + \tau$. In order to account for the volatility of demand, which influences the inventory stocks and thus the production quantities, the value of $\hat{D}_{it+\tau}^P$ is a normally distributed random variable with mean $D_{it+\tau}$ and the exogenously given variance σ_D^2 .

Suppose the firm calculates with price $\hat{p}_{it+\tau}$, with inventory level $S_{it+\tau-1}$, and with output level $\hat{Q}_{it+\tau}$; then, the notional revenue is

$$\hat{R}_{it+\tau} = \min \left[\hat{D}_{it+\tau}^P, \hat{S}_{it+\tau-1} + \hat{Q}_{it+\tau} \right] \cdot \hat{p}_{it+\tau} \quad (3.21)$$

and the stock left over at the end of period $t + \tau$ is

$$\hat{S}_{it+\tau} = \max \left[\hat{S}_{it+\tau-1} + \hat{Q}_{it+\tau} - \hat{D}_{it+\tau}^P, 0 \right]. \quad (3.22)$$

Given the expected change of the environment, the firm computes for each period of the planning horizon the price \hat{p} with the highest period profit. The price adjustment basically follows the same price setting procedure as described in Section 3.2.4.2. A key difference is, however, the determination of the maximum output that the firm can expect to produce in period $t + \tau$. In addition to the feasible output that is limited by the available capital stock, the firm takes a possible rationing at the labor market into account. This means, depending on the labor market tension, the firm cannot expect to fill all open vacancies at a time. Suppose κ_{it}^R is the average share of vacancies actually filled in the last hiring processes and $\Delta \tilde{L}_{it+\tau}$ is the number of additionally desired workers. Then, the expected additional labor is

$$\Delta \hat{L}_{it+\tau} = \kappa_{it}^R \cdot \Delta \tilde{L}_{it+\tau}. \quad (3.23)$$

Incorporating the restricted adjustment of the workforce in the determination of the expected maximum output yields the following expression:

$$\begin{aligned} \hat{Q}_{it+\tau}^{max} = & \sum_{v=1}^V \min \left[\hat{K}_{it+\tau}^v, \max \left[0, \hat{L}_{it+\tau-1} + \right. \right. \\ & \left. \left. + \Delta \hat{L}_{it+\tau} - \sum_{k=v+1}^V \hat{K}_{it+\tau}^k \right] \right] \cdot \min[A^v, \hat{B}_{it+\tau-1}]. \end{aligned} \quad (3.24)$$

Altogether, the notional production quantity for period $t + \tau$ is determined by

$$\hat{Q}_{it+\tau} = \min[\hat{Q}_{it+\tau}^{max}, \hat{D}_{it+\tau} + \hat{\Psi}_{it+\tau} - \hat{S}_{it+\tau-1}], \quad (3.25)$$

where $\hat{\Psi}_{it+\tau}$ is the inventory buffer as described in the price and production planning (see Expression 3.14).

The estimated size of the desired workforce can be derived from the required amount of capital for producing the output quantity $\hat{Q}_{it+\tau}$. We can write $\tilde{L}_{it+\tau}$ as

$$\begin{aligned} \tilde{L}_{it+\tau} = \sum_{v=1}^V \min & \left[\hat{K}_{it+\tau}^v, \max \left[0, \hat{Q}_{it+\tau} \right. \right. \\ & \left. \left. - \min[A^v, \hat{B}_{it+\tau-1}] \cdot \sum_{k=v+1}^V \hat{K}_{it+\tau}^k \right] \right]. \end{aligned} \quad (3.26)$$

The mean specific skill level $\hat{B}_{it+\tau-1}$ in Expression 3.26 is adapted according to the specific skill adaptation procedure described in Section 3.2.3, where the aggregated level of general skills in $t - 1$ is used to estimate the adjustment speed of mean specific skills in $t + \tau$.

In the modeling of the wage determination of incumbent workers, we assume that wages increase in relation to the productivity growth $\hat{p}r$ in the economy (see Section 3.2.6). For this reason, the firm also adjusts the expected wages of its incumbent workforce by the average productivity growth $\hat{p}r$. By contrast, additionally hired workers earn the current wage offer, which is the base wage offer times the effective productivity of the firm. Altogether, we have for the expected mean wage in $t + \tau$

$$\begin{aligned} \hat{w}_{it+\tau} = & \frac{\max[\hat{L}_{it+\tau} - \hat{L}_{it+\tau-1}, 0]}{\hat{L}_{it+\tau}} \cdot w_{it}^{base} \min[\hat{A}_{it+\tau}, \hat{B}_{it+\tau}] + \\ & + \frac{\min[\hat{L}_{it+\tau-1}, \hat{L}_{it+\tau}]}{\hat{L}_{it+\tau}} \cdot \hat{w}_{it+\tau-1}(1 + \hat{p}r_{t+\tau}). \end{aligned} \quad (3.27)$$

For finally determining the net present value of the investment project $I^{v'}$, we define

$$\hat{\Pi}_{it+\tau} = \hat{R}_{it+\tau} - \hat{w}_{it+\tau} \hat{L}_{it+\tau} \quad (3.28)$$

as the estimated profit in $t + \tau$. The net present value is then computed according to

$$NPV_{it}(I^{v'}) = -I^{v'} p_{It}^{v'} + \Delta \hat{\Pi}_{it} + \sum_{\tau=1}^{T^{LT}} \rho^\tau \left(\Delta \Pi_{it+\tau} - \delta I^{v'} \hat{p}_{It+\tau}^{v'} \right), \quad (3.29)$$

where $\Delta \Pi_{it+\tau}$ is the difference of the profit $\Pi_{it+\tau}$ with and without the investment.

If there are investment strategies associated with positive net present values, the firm chooses that strategy with the highest NPV as the candidate strategy for further evaluation. Otherwise, the firm does not invest in the capital stock in period t .

Financial Impact: In the second step of the investment decision, the firm checks the impact of the investment on its financial standing. The available cash is not necessarily sufficient to cover the required investment expenditures. In this case, the firm has to obtain external financing from banks. Bank credits can lead to a liquidity

crisis if the payments for interests and installments exceed the additional cash-flows gained during the pay-back period of the loan. In order to avoid a downgrade of its standing, the firm checks whether the net inflow of the investment covers the financial commitments of the loan during the installment period.

Suppose M_{it-1} is the cash available at the beginning of period t and \hat{L}_{it} is the amount of labor required to produce the estimated output \hat{Q}_{it} , given the investment is about to be realized. Then, the firm estimates its financial requirements \hat{N}_{it} for period t to be

$$N_{it} = I^{v'} p_{It}^{v'} + \hat{L}_{it} \hat{w}_{it} \quad (3.30)$$

and the credit demand \hat{C}_{it} to be

$$\hat{C}_{it} = \max[0, N_{it} - M_{it-1}]. \quad (3.31)$$

In case of required external financing, the firm rejects the investment project as too financially risky if the discounted cash flow including installment and interest payments is negative over the repayment period T^L of the loan, i.e.

$$\Delta \hat{\Pi}_{it} + \sum_{\tau=1}^{T^L} \rho^\tau \left(\Delta \Pi_{it+\tau} - \delta I^{v'} \hat{p}_{It+\tau}^{v'} - \frac{\hat{C}_{it}}{T^L} - i \hat{C}_{it} \cdot \left(1 - \frac{\tau}{T^L}\right) \right) < 0. \quad (3.32)$$

Optimal Timing: If the firm expects the financial risk to be acceptable, it checks in a last step whether it is actually profitable to carry out the investment today or to postpone it to a later date. There is an appealing analogy between a deferrable investment project and financial options - in both cases the option holder has the right but not the obligation to execute the option. Accordingly, a strand of the real option literature suggests to apply well-established option analysis techniques from Finance to those capital budgeting evaluation problems (see Luehrman, 1998).

Benaroch and Kauffman (1999) point out that the validity of these models is often questioned particularly with respect to their theoretical basis and key assumptions. Nevertheless, they present a case study similar to the investment problem of consumption goods firms, in which the firm has the opportunity to defer an investment project. They argue that this problem is analogous to holding an American option on a dividend paying asset, where dividends are foregone revenues during the waiting time. In those cases, a direct application of the Black-Scholes model is not possible but they suggest to use the Black approximation instead (see, e.g., Hull, 2006). In a similar study, Luehrman (1998) presents a framework in which the fundamental Black-Scholes model is used as a practical and 'good enough' rule-of-thumb application of formal option pricing theory to real capital budget problems.

Following the idea of the Management Science approach, we apply the procedure as described in Benaroch and Kauffman (1999) to the consumption goods producer's investment decision. Therefore, we assume that firms explore the opportunity to defer within a fixed time interval of length T^{Ex} . In this case, the firm holds an American option with an expiration date at $t + T^{Ex}$, which can be exercised at any date before T^{Ex} . Those American options can be translated into a portfolio of European options, where one of the European options expires at each month between $t + 1$ and $t + T^{Ex}$. According to the Black approximation, the price O^A of the American option is the maximum value of the European options, i.e.

$$O_{it}^A(T^{Ex}) = \max \left[\{O_{it}(\bar{\tau})\}_{\bar{\tau}=1}^{T^{Ex}} \right]. \quad (3.33)$$

The values $O_{it}(\bar{\tau})$ of the European options can thereby be determined according to the standard Black-Scholes formula. Suppose U is the underlying value of the option's risky asset, i.e. the present value of additional revenues from the investment. If the investment is carried out in $t + \bar{\tau}$, it can be estimated by

$$\hat{U}_{it}(I^{v'}, \bar{\tau}) = \sum_{\tau=\bar{\tau}}^{T-LT} \rho^\tau \left(\Delta \Pi_{it+\tau} - \delta I^{v'} \hat{p}_{I_{t+\tau}}^{v'} \right). \quad (3.34)$$

The project's value in $t + \bar{\tau}$, i.e. its terminal value is then

$$O_{it+\bar{\tau}} = \max\left[\frac{\hat{U}_{it}(I^{v'}, \bar{\tau})}{\rho^{\bar{\tau}}} - I^{v'} \hat{p}_{I_{t+\bar{\tau}}}^{v'}, 0\right]. \quad (3.35)$$

Following Benaroch and Kauffman (1999), the present value $O_{it}(\bar{\tau})$ of the option is the expected discounted terminal value. Assuming that $\hat{U}_{it}(I^{v'}, \bar{\tau})/\rho^{\bar{\tau}}$ is log-normally distributed, it can be shown that

$$O_{it}(\bar{\tau}) = \hat{U}_{it}(I^{v'}, \bar{\tau})N(d_1) - \exp(-\rho\bar{\tau})(I^{v'} \hat{p}_{I_{t+\bar{\tau}}}^{v'})N(d_2), \quad (3.36)$$

where

$$d_1 = \frac{\log\left(\hat{U}_{it}(I^{v'}, \bar{\tau})/(I^{v'} \hat{p}_{I_{t+\bar{\tau}}}^{v'})\right)}{\sigma^V \sqrt{\bar{\tau}}} + \frac{1}{2}\sigma^V \sqrt{\bar{\tau}}, \text{ and } d_2 = d_1 - \sigma^V \sqrt{\bar{\tau}}. \quad (3.37)$$

$N()$ is the cumulative normal distribution and σ^V is the volatility of the expected rate of return on \hat{U} .

After computing the option values for each maturing date $t + \tau$, the firm can determine the total value of its deferring option according to Expression 3.33. The final decision whether or not to realize the investment project by purchasing $I^{v'}$ units of vintage v' of the capital good is positively decided if the net present value of investing today exceeds the value of the deferring option.

3.2.4.4 Firm Entry and Exit

Since there is only one market for consumption goods, firms have no opportunities to find a new business somewhere else. Consequently, entry and exist of firms at the consumption goods market arise only by firm birth and death.

The birth of a firm is assumed to be a random event occurring at an exogenously given hazard rate h^{FB} . At the time of birth, the firm starts from scratch meaning that it does not have initial capital and workers. However, due to the credit acceptance rule of banks, the firm requires a positive equity to obtain credits for building up the capital stock and to hire workers in the first place. To keep the model closed, we assume that a seed funding is provided by a simple kind of venture capital fund. Owners of that fund are the consumption and capital goods producing firms and banks in equal shares such that it is indirectly owned by households. Firms have to pay a small fraction d^F of their monthly positive profit as a payment of contribution as long as the wealth of the fund M_t^F does not exceed a threshold.

In case of a firm birth, the fund provides an initial equity that is s^F times the current capital goods price of the best practice technology, though the payment is restricted by the available cash M_t^F . The memory of a new firm is initialized with average values reported by the statistical office Eurostat. Given the initialization,

a new firm applies the investment and pricing rule as described above and sets the planned output, labor demand, and credit demand accordingly.

The death of a firm arises when a firm has to declare bankruptcy. This is the case when it is either illiquid or insolvent. The former means that the firm is not able to serve its financial commitments, e.g. taxes, interest and debt installment payments, and the later that the firm's total debts exceed its assets.

In case of being bankrupt, the firm follows a bankruptcy procedure that includes as a first step the stop of any production activity and the dismissal of all workers. In a next step, the bankrupt firm tries to liquidate the non-liquid capital assets. Therefore, we assume that there exists a secondary market at which only bankrupt firms can sell and only the capital goods firm can buy the pre-owned capital at a discounted price.

The proceeds of the liquidation are used to pay back the firm's liabilities, where primarily the creditors and secondarily the shareholders are served. In most cases, however, the liquidity will not be sufficient to repay all debts such that the creditors have to write off their claims partially and the firm's shareholders will lose all their investments.

3.2.5 Technological Change

Technological change is modeled in form of embodied technological change as described e.g. by Greenwood et al. (1997). The quality of capital goods is permanently improved through innovations. Productivity gains can be achieved by using capital for production whose productivity is higher than the productivity of the pre-existing capital stock. But due to the inertia of the complementary specific skills, purchasing better capital does not immediately lead to higher productivity (see Section 3.2.3).

Since the focus of our analysis lies on the interactions of the dynamics of labor and consumption goods markets, the capital good sector is modeled in a simplified stylized way. There is a monopolistic capital goods producer that supplies different vintages of the capital good. A vintage v is characterized by its productivity A^v and supplied at infinite supply at a price p_{It}^v .

The capital good can be produced and delivered immediately without input factor requirements and consequently without production costs. In order to close the model the revenues are channeled back into the economy by distributing them to households as dividends.

The development of new vintages with an improved quality is assumed to be a stochastic process. At the beginning of month t , the development of a new vintage is accomplished at an exogenously given and memoryless probability $prob^{Inno}$. In case of a successful innovation, the new vintage becomes the best practice technology where its productivity A^V increases compared to the former best practice A^{V-1} by

$$A^V = (1 + \Delta q^{inv}) \cdot A^{V-1}, \quad (3.38)$$

with being Δq^{inv} exogenously given and $\Delta q^{inv} > 0$.

The pricing of the vintages is modeled as a combination of cost-based and value-based pricing. Although there are no actual costs in the production process of capital goods, we assume as-if costs that the capital goods firm takes into account. The production of a unit of the capital good, regardless of which vintage, is associated with unit costs c_t^C . To account for the cost dynamics, we assume that the main factor of production costs is the wage bill. Since wages increase on average with the same rate as productivity grows, the growth rate of productivity is used as a proxy for the increase in production costs of the capital goods.

Furthermore, we assume that the capital goods firm can observe certain characteristics of its customers and it has certain knowledge of how clients decide on the investment. Moreover, it receives the same market signals as consumption goods firms such that it can estimate the development of the consumption goods market. The capital goods firm uses this information to estimate the average value of one unit of each vintage v for a reference firm whose characteristics, i.e. the set of variables as mean specific skills, average wage etc., match the observed average values of its recent clients. The capital stock of this reference firm is assumed to consist of two vintages, where the quantity of the first vintage K_1 and, respectively, its productivity A_1 is

$$K_1 = (1 - \bar{c}u) \cdot \bar{K} \text{ and } A_1 = \frac{\bar{A}^T - \bar{c}u\bar{A}}{1 - \bar{c}u}. \quad (3.39)$$

In this expression, $\bar{c}u$ is the average capacity utilization, \bar{A} is the average productivity of the used capital stock, \bar{A}^T is the average productivity of the total capital stock and \bar{K} the average size of the capital stock. K_1 reflects the idle capital stock that is not used for production. The second vintage representing the employed capital stock is characterized by

$$K_2 = \bar{c}u \cdot \bar{K} \text{ and } A_2 = \bar{A}. \quad (3.40)$$

The capital goods firm computes the present value of additional profits that the reference firm could generate if its capital stock is expanded by one unit of vintage v . The additional profit is thereby estimated by an analogue procedure as the consumption goods producer's pre-selection of investment strategies described at page 83 ff. The value of v is then estimated according to

$$V_t^v = \sum_{\tau=0}^{T^L} \rho^\tau \Delta \hat{\Pi}_{t+\tau}^v - \max\left[0, \frac{1 - \rho^\tau}{1 - \rho} \cdot \delta \cdot \sum_{\tau=0}^{T^L} \rho^\tau \Delta \hat{\Pi}_{t+\tau}^v\right]. \quad (3.41)$$

The later term in Equation 3.41 reflects that the reference firm expects to keep the capital stock constant over the planning horizon. Thus, besides the initial investments, there are follow-up costs for replacing depreciated capital leading to a reduction of the vintage value.

As a general rule, the price is set at a level that corresponds to the estimated value of the vintage as the capital goods firm interprets the value V_t^v as its costumers' average willingness to pay. There is, however, one exception for which the firm deviates from this rule. It occurs when the value V_t^v is below the unit costs c_t^C . In this case, the vintage is not offered in t . It might be the case that all values of the vintages are below c_t^C , though. Then, only the best practice technology is supplied at a price corresponding to the unit costs c_t^C .

Altogether, we can write the price setting rule as

$$p_{It}^v = \begin{cases} 0, & \text{if } v < \check{v} \text{ and } V_t^v < c_t^C, \\ V_t^v, & \text{if } v \leq \check{v} \text{ and } V_t^v \geq c_t^C, \\ c_t^C, & \text{if } v = \check{v} \text{ and } V_t^v < c_t^C, \end{cases} \quad (3.42)$$

where \check{v} denotes the best practice technology.

There are two implications of this price setting rule. The first is that the capital goods firm realizes that out of date vintages, i.e. those vintages with productivity significantly below the average productivity of costumers' capital stock and

workforce, do not have any value for the clients. Consequently, those vintages are withdrawn from the market. The second implication is that capital goods prices react to changes of expectations of consumption goods firms concerning the market performance. Thus, prices are higher in prospering than in economically bad times.

3.2.6 Labor Market Interaction

Based on the planned output and the available financial resources, consumption goods producers determine the labor demand \tilde{L}_{it} for the current production cycle t . If the workforce employed at the beginning of t is not sufficient to cover the required labor demand, firms enter the labor market in order to recruit new employees. Therefore, they post vacancies that can be read by job searchers.

The wage offer plays an important role in the hiring process. In an ideal world firms would pay workers an individual wage that matches the productivity level of each worker perfectly. But as the productivity of applicants is assumed to be unobservable, they cannot directly link the wage to the individual productivity. What firms can, however, observe is the general skill level of applicants. Furthermore, they can monitor the productivity of the incumbent workforce in total and the averages for the two general skill groups separately. By interpreting the general skill level g as a signal for the productivity, firms expect the specific skills of applicants to be at the average level \bar{B}_{igt-1} of incumbent workers belonging to the same skill group as the applicants do. For each general skill group g , firms post a separate wage offer w_{igt}^O that is determined according to

$$w_{igt}^O = w_{it}^{base} \cdot \min[A_{it}, \bar{B}_{igt-1}]. \quad (3.43)$$

The first factor w_{it}^{base} of the right-hand site represents a market driven base wage offer that is paid per unit of specific skills. The second factor is the effective productivity that a new worker is expected to yield. Effective productivity means that, due to the assumed complementarity, high specific skills cannot be fully utilized if the capital stock does not have a sufficient productivity, i.e. $A_{it} \geq \bar{B}_{igt-1}$. In those cases, firms are unwilling to pay wages that correspond to their actual labor productivity and limit the wage offers accordingly.

Unemployed workers accept only those job offers whose salary exceeds a reservation wage w_{ht}^R . When becoming unemployed, the reservation wage is set at the level of the last earned wage and, as long as the household cannot find a new job, it declines over time by

$$w_{ht+1}^R = (1 - \psi) \cdot w_{ht}^R. \quad (3.44)$$

Note that the reservation wage cannot fall below the level of unemployment benefits, which itself is a fraction u of the last labor income.

The labor market interaction between households and firms is described by a simple two-round search-and-matching algorithm. In the first step, firms post vacancy notifications that can be read by unemployed households. Job seekers consider the posted wages w_{igt}^O for the skill group they belong to and send applications for those jobs whose wage offers exceed the reservation wage. The number of applications per workers is thereby limited. In the next step, firms collect all applications and decide based on a logit discrete choice model which applicants to send a job offer. A parameter γ^{gen} of the logit model specifies the weight that general skills have in the decision process. Finally, households getting one or more job offers become re-employed, where households with more than one offer accept that one associated with the highest wage and reject the others. Thus, it is not ensured that firms can

fill all vacancies. At the same time, there might also be households that have not received any job offers.

Both, rationed firms and households, have a second opportunity to be matched in a second round of the labor market procedure. Before reentering the labor market, the rationed firms increase their base wage offer w_{it}^{base} by

$$w_{it}^{base} = (1 + \varphi) \cdot w_{it}^{base}. \quad (3.45)$$

This should account for the fact that firms that have failed to fill vacancies try to attract new workers by raising their wages.

In the opposite case, when the labor demand is lower than the number of workers employed at the beginning of t , firms have to make redundancies. They expect that high-skilled workers have either higher specific skills or, at least, are capable of learning faster while working with more productive technologies. Therefore, firms dismiss workers with low general skills first. Additionally, there is a small probability for each worker-employer match to be separated in each period. This should capture job separation due to reasons not explicitly captured in the model.

Not only the wage of new workers but also the wage of the incumbent workforce is linked to the productivity. By assuming that the wage keeps pace with the productivity growth in the economy, the individual wage of a worker h changes according to

$$w_{ht} = (1 + pr_{t-1}) \cdot w_{ht-1}, \quad (3.46)$$

where pr_{t-1} is the average productivity growth achieved in the previous period $t - 1$.

3.2.7 Consumption Market Interaction

There is a considerable degree of uncertainty regarding the household's monthly income stemming from two sources. The first source is the labor income that can rapidly change by being fired or hired. The second source of uncertainty is the capital income that depends on fluctuating dividend payments of firms. For a saving and consumption decision with uncertain income, a strand of the consumption theory literature describes models with buffer stock saving in which households undertake precautionary saving in order to preserve them against bad future incomes. This theory is also supported by empirical evidences (see, e.g., Carroll and Summers, 1991; Deaton, 1991).

For determining the consumption budget, households apply a linear approximation of an optimal buffer stock saving rule as described in Allen and Carrol (2001). The desired buffer stock depends on the current income and is determined by a target ration Φ of wealth to income. As long as the actual wealth matches the desired buffer, a household would completely spend the monthly income for consumption. In case the actual size of the wealth deviates from the planned buffer, the household reacts by increasing or decreasing the monthly consumption budget relative to the income, depending on the deviation of the wealth from its target. A parameter κ indicates how sensitive the consumption reacts on the deviation. The rule can be written as

$$C_{ht}^{exp} = I_{ht} + \kappa(W_{ht} - \Phi I_{ht}), \quad (3.47)$$

where I_{ht} is the monthly income consisting of labor or unemployment benefits, respectively, as well as dividend payments. W_{ht} is the wealth consisting of money holdings and asset wealth in shares.

The consumption goods market is represented by a central outlet mall in which consumption goods producers offer and sell their goods to households. Households

visit this outlet mall once a week and try to spend the entire weekly budget for one good. The days at which they go to the mall are randomly distributed among households. In the mall, the customers can observe the prices but they do not get information about the available quantities. The purchasing decision of households is described using a logit model as suggested in the Marketing literature (see, e.g., Malhotra, 1984). The relative price of goods is an important factor influencing the outcome of the decision, where the intensity of choice with respect to the prices is set by a parameter γ^C .

Since firms have inflexible production cycles they can refill the mall inventories only once per month. Furthermore, the individual delivery dates of firms are asynchronized. Thus, the supply is strictly limited by available inventory stocks and, since the households have no information on the inventories, there is the possibility to be rationed. In this case, the mall sets a rationing quota corresponding to the percentage of the total demand that can be satisfied with the available goods and each household gets the indicated percentage of the requested consumption. Rationed households have a second chance to spend the remaining budget for another good.

3.2.8 Parametrization and Initialization

The model hosts a considerable number of parameters. In order to determine a parametrization used for the simulations, we follow an approach that combines a direct estimation of parameters for which empirical observations are available with an indirect calibration approach. Calibration means we use the degrees of freedom stemming from parameters without empirical counterparts to tweak the model in such a way that it generates economically accurate simulation outcomes. This facilitates the ability of the model to capture economic mechanisms which are relevant for real world economic dynamics. Table 3.1 provides an overview of the standard constellation of model parameters obtained from the empirically grounded calibration procedure.⁵ Besides the parametrization, the table also shows the set-up of the model regarding the number of agents of each type, the general skill distribution among households and the adjustment speed of specific skills for the general skill groups.

In Section 3.5 we provide a detailed sensitivity analysis for the parameters listed in Table 3.1. By changing the model parameters within a given range, we can identify possible effects of these parameters on key economic variables as e.g. the output growth and can, therefore, assess the sensitivity of the model with respect to the choice of parameters.

In the model, technological change is one of the main drivers of long-term economic growth, where the technological development is mainly determined by the growth of the technological frontier and the diffusion of technologies. To avoid spurious growth effects stemming from stochastic differences in the dynamic of the technological frontier between runs, we use an identical realization of the stochastic process governing the emergence of new vintages in all considered runs.

Agent based models are typically characterized by strong path dependencies. Therefore, the initial state of the system, which is an exogenous input to the si-

⁵Table 3.1 shows all parameters that are mentioned in the model description and their values used for the simulations. Additionally, the table lists some parameters especially for the credit and financial market that are not explicitly discussed in this paper but are listed for the sake of thoroughness. For a detailed description of those parameters, the reader is referred to Dawid et al. (2012b).

Symbol	Name	Value
<u>Agents</u>		
	Households	1600
	Firms (initially)	80
	Investment good producers	1
	Banks	2
	Central Bank	1
	Government	1
<u>General skill distribution</u>		
$b_h^{gen} = 1$	Low-skilled workers	50%
$b_h^{gen} = 2$	High-skilled workers	50%
<u>Specific skill adaptation speed</u>		
$\chi(b_h^{gen} = 1)$	Speed for low-skilled workers	0.0125
$\chi(b_h^{gen} = 2)$	Speed for high-skilled workers	0.03703
<u>Parameters</u>		
tax	Income tax rate	0.025
κ	Consumption adjustment	0.001
δ	Capital depreciation rate	0.01
χ^S	Service level expected demand	0.7
γ^C	Intensity of consumer choice	12.0
ρ	Discount rate	0.02
Δq^{inv}	Technological progress	0.05
T^{Ex}	Maximum deferral period	24
σ^V	Demand volatility	0.1
T^{LT}	Investment planning horizon	60
σ_D^2	Expected variance	0.1
T^{Loan}	Debt repayment period	18
ω	Debt rescaling factor	0.50
r^c	ECB base rate	0.03
mr^c	ECB rate markdown deposit rate	0.1
d^f	Dividend payout ratio	0.70
\bar{d}	Threshold full dividends (firms)	0.5
α^b	Basel capital requirement	10.0
β^b	Min. cash reserve ratio	0.10
h^{FB}	Firm birth hazard rate	0.01
s^F	Initial equity for start ups	4.0
φ	Wage update	0.01
ψ	Wage reservation update	0.01
ϱ^{up}	Upper bound firing	0.1
γ^{gen}	Logit parameter general skills	0.5
u	Unemployment benefit pct	0.55

Table 3.1: Set-up and parametrization of the model.

mulation, can have considerable effects on the simulation output. This makes the choice of the initial state to a crucial one. In general, there are several conditions that constrain the initialization of agents' state variables. First and foremost, the initial values of the variables should be plausible in order to avoid odd initial states generating economically unreasonable simulation outcomes. Second, we have to consider several interdependencies of variables. Especially with respect to the balance sheet of agents, we have to initialize the variables according to the criterion of stock-flow consistency. If the balance sheets are inconsistent from the start, they would remain so throughout the entire simulation. Thus, we are constrained to set the initial values in such a way that the balance sheet relationships between agents hold (a deeper discussion of these constraints can be found in Dawid et al., 2012b).

We set up the model in such a way that the agents are initially homogeneous with respect to most characteristics. Firms have identical assets (a capital stock of the same size and quality, and the same amount of liquidity) and liabilities, and there are no established worker-employer matches. Households own the same wealth and are endowed with the same specific skills. The general skills of households are heterogeneous and distributed according to the distribution reported in Table 3.1.

After a simulation has started, the distributions of certain variables of agents such as firm size, capital productivity or households' wealth evolve endogenously over time. Whether the properties of the emerging distributions match empirical distributions can be considered as a proof for the validity of the model.

It should be clear that any initialization has invariably transient effects but these transient effects level off with elapsing simulation time. In order to alleviate that those transient effects distort the policy experiments, we use a start state of the economy for the simulations which is already settled. Therefore, we have run a pre-simulation based on the initial state described above and chosen a post-transient snapshot of this simulation as the initialization for all simulations considered in the following sections.

3.3 Business Cycle Properties and Stylized Facts

In this section, we present some properties of a representative simulation run generated with the default parametrization of the model. The aim is to demonstrate that the model described in Section 3.2 generates simulation outcome with realistic properties, thereby replicating various empirical stylized facts. The ability of a model to replicate stylized facts is one possibility to verify the model. Our focus is on the ability to generate endogenous business cycles with realistic properties, which can be seen as proof of its applicability for considering policy questions regarding the stabilization of business cycles.

Figure 3.1 shows the main macro variables output, annual output growth rates, inflation and unemployment rate. From panel (a) and (b), one can clearly see that the model generates endogenous business cycles. Output dynamics are characterized by persistent fluctuations and growth with a business cycle component around the trend. The long-term annual growth rate is 1.6% while over the business cycle the growth rate deviates considerably from its long-term average. The volatility of the business cycle⁶ can be measured by computing the percentage standard deviation of the cyclical component. Therefore, the time series has been detrended by means of the HP filter with $\lambda = 1600$, which is a standard choice for a business cycle analysis

⁶The volatility of the business cycle is of particular interest in Section 3.4, in which different policies with the goal of reducing the business cycle volatility are discussed.

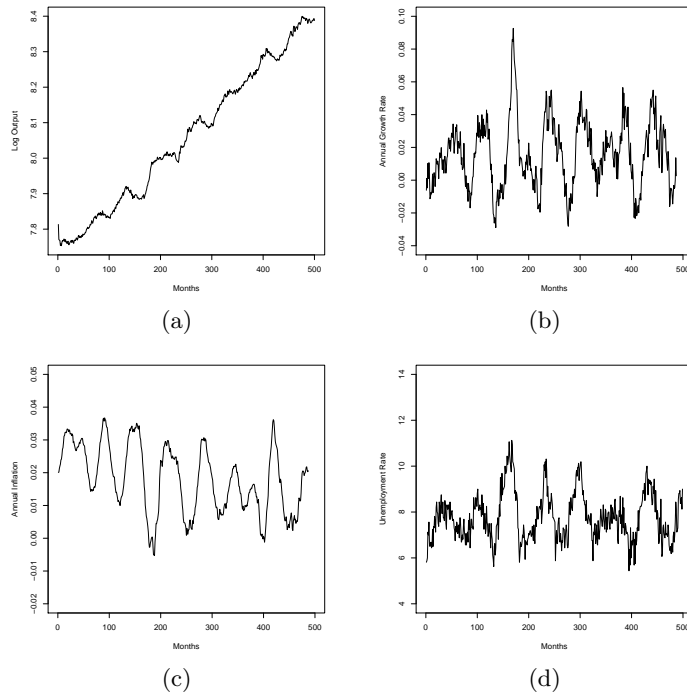


Figure 3.1: Time series of (log) output (a), annual growth rate (b), annual inflation rate (c), and unemployment rate (d).

of quarterly data (for more details, see, e.g., Hodrick and Prescott, 1997). The relative standard deviation is 1.54% for the representative simulation run. Sorensen and Whitta-Jacobsen (2005), for example, report a volatility of 1.66% for the U.S. business cycle between 1955 and 2001, hence the volatility generated by the model matches the empirically observable values substantially.

A further property of the business cycle is its persistence. Persistence describes the dependency of the level of output in period t from its previous realizations and is typically measured by the one-quarter auto-correlation. The auto-correlation coefficient of the cyclical component of output is 0.9. A value of 0.9 implies that the business cycle is highly persistent. This observation is also in accordance with empirical observations (see again Sorensen and Whitta-Jacobsen, 2005, who report a value of 0.86 for the U.S. economy).

The average length of the detected business cycles is about 21 quarters (corresponding to 5.25 years) with a minimum length of 17 quarters and a maximum of 24 quarters. This is within the range of 6 to 32 quarters, which is customarily used for defining business cycles in the empirical literature (see, e.g., Baxter and King, 1999). Moreover, Figure 3.1 shows a persistent inflation, fluctuating in a corridor between -0.5 and 4% with a mean of 1.8% (panel c). Also the unemployment rate fluctuates, where its range is between 5.5 and 11.2% with a mean of 7.8% (panel d).

The empirical business cycle literature examines the relationship between the aggregate business cycle and various other macroeconomic variables, such as prices, wages, employment, productivity, investment, and consumption. A broader discussion of business cycle properties of 71 U.S. economic time series can be found in Stock and Watson (1999). Table 3.2 on page 97 summarizes the business cycle properties for a set of economic time series of the benchmark simulation. The second column of the table shows the volatility by means of percent standard deviation as

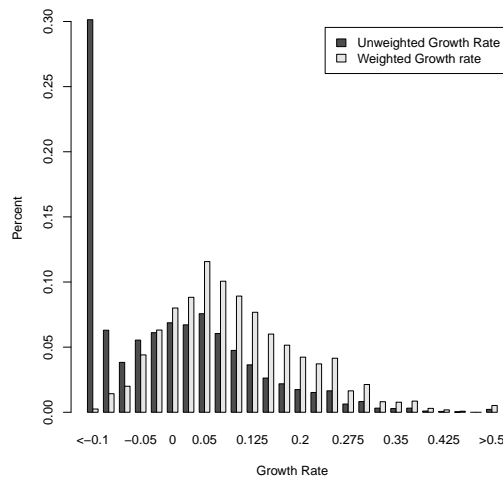


Figure 3.2: Capital growth rate distributions; unweighted and weighted by investment.

described above and the remaining columns indicate the co-movement of the variables with GDP. The co-movement is measured by cross-correlations $Cor(x_t, y_{t+k})$ of the cyclical component of a time series x with the cyclical component of output, y . A large positive correlation at $k = 0$ indicates procyclical co-movement and a large negative correlation countercyclical behavior. A maximum correlation at, for example, $k = -1$ indicates that the cyclical component of series x tends to lag the aggregate business cycle (series y) by one quarter.

From Table 3.2 one can see that the total consumption is procyclical and almost as volatile as output, where in contrast to the empirical findings, the consumption is more volatile. The volatility of investments is considerably higher than the volatility of consumption and output, a fact that is often reported (see, e.g., Stock and Watson, 1999). A difference can be seen in the co-movement of investments and output. While the empirical literature observes coincidence, investments lead the business cycle in the baseline simulation. But the cyclical component of the capital stock is strongly procyclical in the simulation.

Lumpiness of investments at the firm level is a frequently reported stylized fact for the capital accumulation (see Dosi et al., 2006). Based on U.S. plant level data, Doms and Dunne (1998) show that 51.9% of plants expand their capital stock by less than 2.5% in a year, while 11% of plants increase their capital stock by more than 20% within the same time interval. Figure 3.2 presents two distributions generated from the benchmark simulation, the density of annual capital growth rates of all firms and the density of the growth rate weighted by firms' investment (see Doms and Dunne, 1998, for more details). The figure shows that 59% of firms invest less than 2.5% within a given year, while 7% of firms increase their capital stock by more than 20%. However, these 7% significantly contribute to the aggregated investment. The weighted density shows that these firms account for 20% of the total investments. At the other end of the distribution, the 59% of firms, which increase the capital stocks by less than 2.5%, contribute to about 22% of the overall investment. This suggests that, in accordance with empirical evidences, the investment behavior of firms in the model is characterized by a considerable lumpiness.

The labor market indicators behave as one would expect: employment is strongly

	Cross Autocorrelations with $(Cor(x_t, y_{t+k}))$													
	Std Dev	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
Output	0.015	-0.19	0.06	0.31	0.54	0.74	0.90	1.00	0.90	0.74	0.54	0.31	0.06	-0.19
Consumption	0.016	0.34	0.47	0.58	0.66	0.72	0.77	0.71	0.56	0.37	0.16	-0.06	-0.29	-0.50
Investment	0.554	-0.35	-0.40	-0.40	-0.36	-0.33	-0.24	-0.02	0.24	0.30	0.32	0.39	0.39	0.39
Capital stock	0.025	-0.26	-0.02	0.23	0.47	0.68	0.86	0.97	0.90	0.75	0.56	0.35	0.11	-0.12
Unemployment rate	0.107	0.19	-0.05	-0.28	-0.49	-0.68	-0.84	-0.97	-0.86	-0.73	-0.56	-0.37	-0.14	0.12
Employment	0.009	-0.19	0.05	0.29	0.49	0.69	0.85	0.97	0.87	0.73	0.56	0.36	0.13	-0.13
Vacancies	0.110	-0.26	-0.07	0.14	0.37	0.57	0.75	0.84	0.83	0.70	0.51	0.33	0.11	-0.09
Price index	0.007	-0.67	-0.83	-0.91	-0.92	-0.84	-0.69	-0.48	-0.22	0.03	0.27	0.49	0.65	0.75
Nominal wage	0.004	0.79	0.77	0.67	0.52	0.33	0.12	-0.13	-0.40	-0.61	-0.74	-0.79	-0.81	-0.75
Productivity capital stock	0.008	-0.26	-0.04	0.20	0.43	0.61	0.79	0.89	0.84	0.69	0.50	0.31	0.10	-0.11
Specific skills	0.002	0.70	0.82	0.88	0.86	0.77	0.60	0.37	0.09	-0.17	-0.41	-0.61	-0.74	-0.81
Private Debt	0.284	-0.75	-0.62	-0.41	-0.16	0.13	0.43	0.69	0.81	0.84	0.81	0.72	0.57	0.37
Markup	0.090	0.42	0.16	-0.13	-0.40	-0.62	-0.79	-0.88	-0.82	-0.70	-0.52	-0.35	-0.16	0.04
Herfindahl index	0.010	-0.11	0.09	0.29	0.47	0.61	0.67	0.68	0.63	0.56	0.42	0.24	0.05	-0.14

Table 3.2: Percent standard deviations of the cyclical component of the time series (second column) and cross-correlations of the cyclical components of each time series with the cyclical component of output, led k periods (other columns).

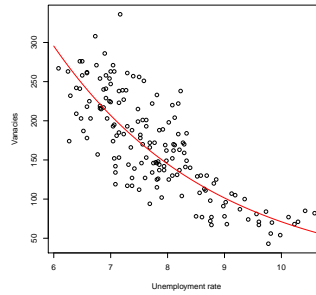


Figure 3.3: The Beveridge curve approximated by means of a log-linear regression.

procyclical and, as a direct consequence, the unemployment rate is strongly countercyclical. During boom phases, firms tend to expand their workforce while during recessions they need to reduce the number of workers. This pattern is also reflected by the strongly procyclical co-movement of vacancies. The empirical relation of unemployment and the amount of open jobs is typically summarized in the Beveridge curve, where a negative correlation between unemployment rates and the number of open jobs is an empirical fact (see, e.g., Blanchard et al., 1989). Figure 3.3 shows a clearly downward sloping Beveridge curve for the simulation run, which indicates that the model is able to generate a negative relationship between unemployment rate and number of vacancies.

Total credit moves procyclical leading the cycle by two quarters, which shows that private debt expands during booms and contracts during a decline. This indicates that the primary reason for firms to increase debt is to finance expansion of production rather than to re-finance already existing debt.

A further observation is that the Herfindahl index, which is a measure for the market concentration, moves coincidentally with the business cycle. This suggests that during boom phases firms expand their production volumes unequally. Thus, some firms can increase their market shares at the expense of other firms, which leads to an increased market concentration. As a result, the different growth patterns generate heterogeneity of firms with respect to firm sizes. Despite sector specific differences, the empirical literature on firm size distributions reports a common regularity, namely the tendency of firm size distributions to be right-skewed with upper tails made of few large firms (see, e.g., Dosi et al., 2006). Panel (a) of Figure 3.4 shows the simulated firm size distribution in a Log Rank vs. Log Size plot, where output is used as a proxy for firm size. The actual firm size distribution is represented by circles while the solid line shows the log-normal distribution with the sample mean and standard deviation as distribution parameters. The plot indicates that the firm size distribution is close to the log-normal distribution so that it is characterized by a considerable right-skewness. It should be noted that the firm size distribution in panel (a) is based on a snapshot of the simulation at month 250; in panel (b) we show the evolution of the firm size distribution over time. This panel indicates that the right-skewness of the distribution is persistent.

Coming back to the co-movement of variables, Table 3.2 shows the co-movement of the price index, nominal wages, and two measures of productivity, the productivity of the capital stock and the average level of specific skills of the employed workers. The price index is countercyclically lagging the business cycle and for the wage, there is no significant cross correlation. Stock and Watson (1999) report coun-

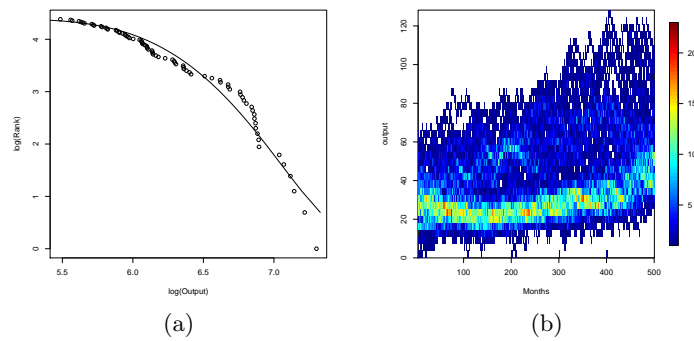


Figure 3.4: Firm size distribution; Log Rank vs. Log Size plot of firm output (a) and evolution of output distribution (b). The color code indicates the density of the population distribution in the considered range of the variable output.

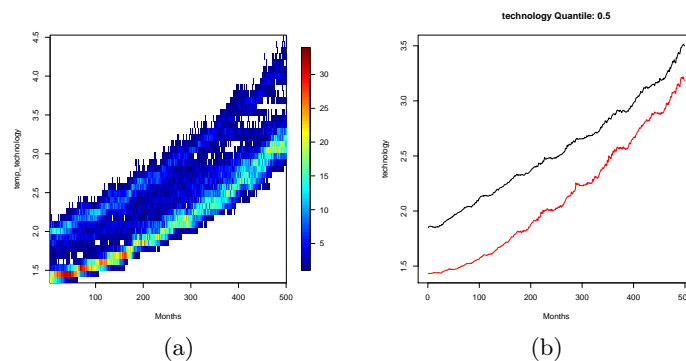


Figure 3.5: Evolution of the productivity distribution (a) and evolution of average productivity of firms that are low-productive (red) and high-productive (black) at $t = 100$ (b).

tercyclical and leading co-movement for wages and prices. For the co-movement of productivity, we find a procyclical evolution for both measures, which is consistent with the findings in Stock and Watson (1999).

The productivity dynamics of firms generated by the model shows some characteristics which are widely described in the empirical literature (see again Dosi et al., 2006). Figure 3.5 (a) depicts the evolution of the productivity distribution over time where productivity is measured as the productivity of the utilized capital stock. Besides the general increase of the average productivity due to technological progress, this figure indicates that there is considerable productivity dispersion among firms and the distribution, as that of firm sizes, tends to be right-skewed. Panel (b) indicates a high persistence of productivity differentials between firms which is a further empirical regularity reported by Dosi et al. (2006). The panel shows the evolution of the average productivity of two subgroups of firms, which belong either to the lower 50% quantile (red line) or to the upper 50% quantile (black line) of the technology distribution at months 100. Evidently, there is only little technological catch up of the lagging firms. Firms that have belonged to the group of low-tech firms in an early phase of the simulation show a high probability to remain low-tech throughout the simulation.

Unlike in most standard macroeconomic models, the mark-ups are determined endogenously at the firm level and change over time. As it can be seen in Table 3.2, mark-ups tend to move countercyclical. It has been argued in Blanchard (2008) that,

indeed, there is empirical indication of countercyclical mark-ups (see Bils and Chang, 2000) and that it is a wide open macroeconomic research question to provide sound theoretical explanations for the movement of mark-ups along the business cycle.

3.4 The Policy Analysis

3.4.1 Policy Design

The previous section has demonstrated that the model generates endogenous business cycles with realistic properties, thereby replicating important stylized facts of micro- and macroeconomic dynamics. In this section we employ this model in order to carry out policy experiments in which we investigate the effectiveness of fiscal policy measures that aim at smoothing the business cycle volatility.

As pointed out in the introduction, the U.S. administration of President George W. Bush and Barack Obama enacted 2008 and 2009 two stimulus packages of considerable size in response to the world economic crisis started in 2008. Both packages contained, among others, tax rebates to households as a stimulus for private consumption as well as direct and indirect investment subsidies to business firms. The investment policies of the two programs differed from each other by a varying technological targeting. While the package of 2008 aimed at basically stimulating any investment by changed tax treatments of investment costs and capital depreciation, the economic stimulus plan of 2009 had a stronger focus on those investments supporting the technological advance of the U.S. economy. Broadly speaking, the different policy measures of the two packages can be summarized under three distinct policy categories; demand subsidization, investment subsidization, and technology subsidization. We mimic these policies in a highly stylized way and try to address the following research questions in three independent policy scenarios: Are these three policies actually able to smooth the business cycle? Do the policies have long-term effects on the growth path of the economy? And finally, is the financing of the policies self-sustained or must the government finance them separately?

In the policy analysis we abstract from problems associated with time lags in detecting recessions and implementing policies and also from other issues of the political economy. Therefore, even if we interpret the policies as discretionary, we implement them in a rule-based fashion. With rule-based we mean that the stabilization policies are automatically introduced and adjusted when there is a risk of the economy to plunge into an economic crisis. Therefore, we define a threshold growth rate g^{th} at which the policy is automatically installed if the quarterly growth rate g_{t-1}^Q of the last period is below this threshold.⁷ In order to achieve the stabilizing effect, the expansion of the policies are adjusted depending on the deviation of the last-period growth rate from the threshold.

The first of the considered policies is a classical demand-oriented Keynesian stimulus. The aggregate demand is increased by stimulating consumption through a direct subsidization of households. When the quarterly growth rate is below the critical growth rate, all households receive a subsidy, where the individual subsidy is a percentage s_t^{HH} of the household's current monthly consumption budget. As pointed out above, we assume that the subsidy rate s_t^{HH} increases with the gap

⁷The target growth rate is set such that it corresponds to the average growth rate of the technological frontier, which can be interpreted as the natural growth potential of the economy. As will be pointed out below, the frontier grows at an annual rate of about 2%. Thus, the threshold value at which the policy is activated is $g^{th} = 0.005$.

between the actual and the threshold growth rate. Thus, the larger the deviation of the growth rate from g^{th} , the more subsidies are paid out to households. The size of the subsidy rate is determined according to the following equation:

$$s_t^{HH} = \mu \cdot \tanh \left(\max \left[0, g^{th} - g_{t-1}^Q \right] \right). \quad (3.48)$$

Besides the deviation of the quarterly growth rate from the threshold g^{th} , the size of the subsidy rate depends on an exogenous parameter μ . This parameter is used in the policy experiments to control the intensity of the policy (see below).

We assume that households know the conditions of the policy ex ante and take the subsidy as additional budget into account when deciding about consumption plans. It is not possible to retain and save the subsidies because households have to spend subsidies immediately.

The second policy is a subsidization of firms' capital investment. When the policy is implemented, all investing firms receive a fraction s_t^{Inv} of their investment expenditures as subsidies. Again, we assume that firms know the conditions of the policy ex ante and incorporate the subsidy in their investment decision by taking a reduced capital price into account. The subsidy percentage s_t^{Inv} is determined according to the same rule as described in Expression 3.48.

The third policy scenario also considers an investment subsidization, but in contrast to the second policy, firms receive subsidies only if they choose the currently available best practice technology for their investment. As for the other policies, the subsidy rate s_t^{Tech} is determined according to Equation 3.48.⁸

We set up simulations in which we vary the intensity parameter μ incrementally by steps of size 0.25 within an interval between null and a maximum level μ_{max} . This enables us to examine a quasi-continuation of policy effects and allows a better analysis and comparison of the three policies. The maximum intensity is different for each policy and is chosen such that a further increase does not lead to a significant reduction of business cycle volatility. We have $\mu_{max} = 12.0$ for the consumption policy, $\mu_{max} = 28.0$ for the investment policy, and $\mu_{max} = 20.0$ for the technology policy.

We run 12 batch runs for each of the considered values of μ . With $\mu = 0$ no policy is applied; this case is the baseline scenario and is considered in the following subsection in more detail. When $\mu > 0$, then one of the three stabilization policies is implemented, where the intensity of the policy differs depending on the parametrization of μ . It should be noted that identical values of μ for different policies do not imply quantitatively comparable policy scenarios.

3.4.2 The Baseline Scenario With No Policies

Before we start the discussion of the policies, we consider the baseline scenario in more detail. For the baseline scenario, we have 12 independent simulation runs that are based on the same parameter setting and initial condition. Nevertheless, since each single run represents the outcome of a Monte Carlo process, there can be a considerable variance among the runs. In order to demonstrate generic properties of the baseline case and to eliminate spurious effects stemming from statistical outliers, we consider aggregated time series of economic variables in the following discussion. Therefore, we have pooled the 12 single time series of a particular variable under

⁸Applications of the latter two policies are considered in Dawid et al. (2014) in the context of cohesion policies within a two region setup of the Eurace@Unibi model.

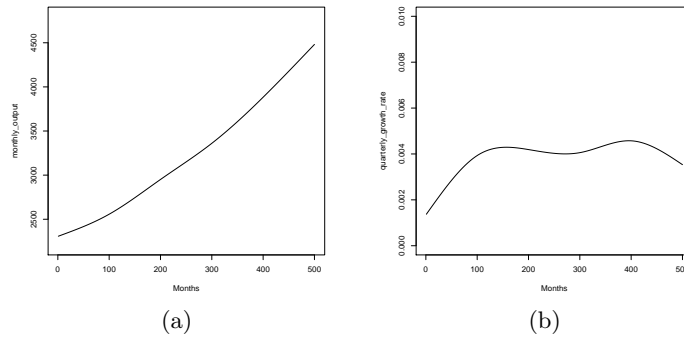


Figure 3.6: Spline smoothed evolution of the trajectory of aggregated output (a) and quarterly growth rates (b).

study and estimated a statistical representation of the whole batch by using Generalized Additive Models (GAM) with penalized splines (see, e.g., Wood, 2011, for more details). Predictions of the estimated GAM⁹ given by

$$g_t = g_0 + s(t) \quad (3.49)$$

are used as the aggregated representation of the time series. In this expression, g is the response variable that is distributed following some exponential family distribution, time t in months is the covariate of the statistical model and g_0 is a parametric intercept. The term $s(t)$ is an unknown smooth function that depends on covariate t . The GAM yields a smoothed time series for the considered variable in which those interferences are filtered out that might arise by shifted business cycles waves between batch runs.

With no policy treatment the simulation of the model with 12 runs yields output trajectories that are represented by the time series in Figure 3.6 (a). One can see that the positive trend observed for the output trajectory in the discussion of the single run in Section 3.3 seems to be a generic feature of the simulation. If the short-term business cycles are statistically smoothed out, the economy shows persistent growth at an average annual rate of 1.61%. Recall that we have observed an average growth rate of 1.6% for the illustrative single run in Section 3.3. Furthermore, the average business cycle volatility of the batch is with about 1.65% also close to the value 1.54% described in Section 3.3.

Panel (b) depicts the evolution of the quarterly growth rates of the economy. Apparently, the smoothed growth rates are not constant over time. This suggests that the simulation generates not only short-term volatility but also long-term dynamism. The economy is characterized by a persistent disequilibrium rather than by a quasi-equilibrium with constant long-term growth around which the business cycle fluctuates in the short run. This observation is also supported when looking at other macroeconomic variables. Panel (a) of Figure 3.7, for example, depicts the evolution of the unemployment rate. After smoothing out short-term fluctuations, the unemployment rate evolves dynamically in long waves. The lowest unemployment rate can be observed at the beginning of the simulation and the highest between month 300 and 400. Similarly, the (smoothed) quarterly inflation rate varies over time, where it has its highest level at the outset. This is plausible as at the same time also the labor market tension is high. Firms have difficulties to fill open vacancies

⁹We have used the function `gam` of the `mgcv` package in `R` for estimations of Generalized Additive Models in this paper. An introduction how to estimate GAMs in `R` can be found in Wood (2006).

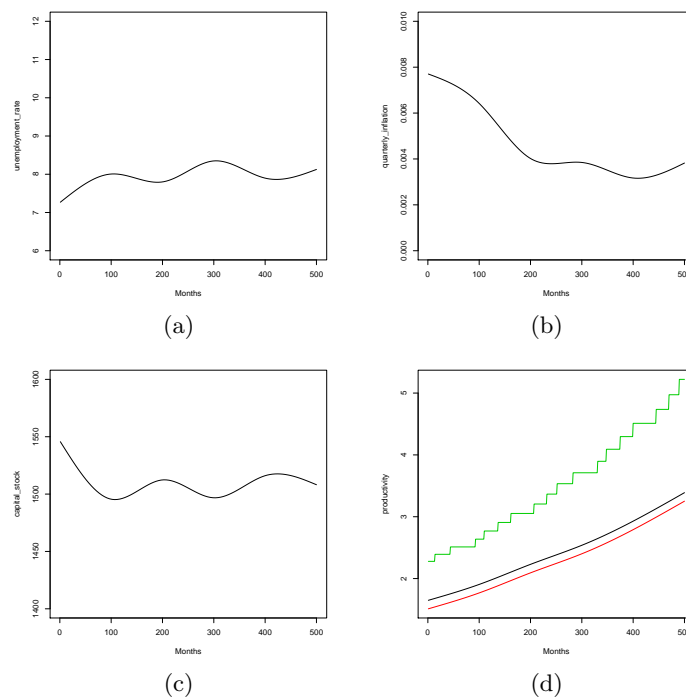


Figure 3.7: Spline smoothed evolution of the trajectory of unemployment rates (a), quarterly inflation rates (b), capital stock (c); panel d: spline smoothed evolution of capital productivity (black), specific skills (red) and the unsmoothed evolution of technological frontier (green).

so that a dynamical change of base wage offers emerges that drives unit costs up and eventually results in higher inflation. As time elapses, the unemployment rate becomes gradually higher, which takes some pressure off the labor market. With the increasing unemployment rate also the inflation rate declines.

The evolution of the aggregated capital stock in panel (c) mirrors the evolution of the unemployment rate, which is a consequence of the assumed complementarity of labor and capital. In panel (d) we show the evolution of the productivity in the economy. The green line displays the evolution of the technological frontier, whose average annual growth is at about 2.01%.¹⁰ The other two lines show the evolution of the average productivity of the employed capital (black line) and the average specific skills of workers (red line). Apparently, there is a persistent gap between the capital productivity and the productivity of workers. This gap can be explained by the fact that the learning process of employees takes time. Furthermore, the panel shows that specific skills are the limiting factor within the complementary relation of physical and human capital.

The average annual growth rate of the specific skills is 1.87% and the growth rate of the productivity is 1.74% p.a. This means that the gap between specific skills and the capital productivity tends to become closer. At the same time, the growth of the aggregated productivity is lower than that of the frontier so that the average productivity and the frontier diverge over time. Compared to the aggregate output, the growth rate of the productivity is higher so that the output growth can

¹⁰Note that, as discussed above, the innovation process within the capital goods sector is modeled as a stochastic process. In the simulations, however, we use an identical realization of this process in each simulation run.

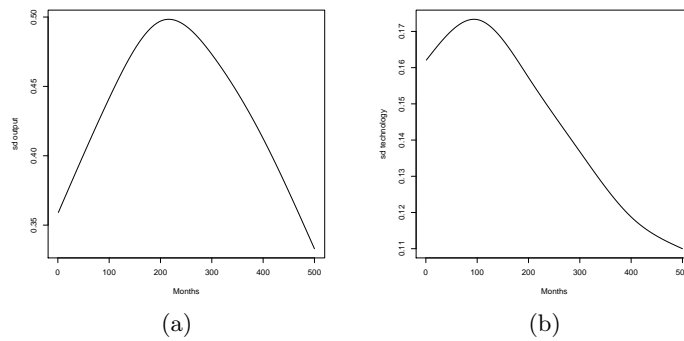


Figure 3.8: Spline smoothed standard deviations (in percent of the mean) used as an indicator for the heterogeneity of firms with respect to firm size (a) and technological productivity (b).

largely but not completely be explained by the speed of technological progress in the economy.

In Section 3.3 we have already considered the distributions of firm sizes and productivity. For both variables we have found a right-skewness in the heterogeneity. The productivity distribution seemed to be persistent over time so that low-productive firms catch up to the technological leaders only at a very low speed. In Figure 3.8 we depict the evolution of indicators for the heterogeneity of both distributions. In this figure, panel (a) shows the relative standard deviation of firms' output and panel (b) the relative standard deviation of the capital stock productivity. Both panels indicate a non-stationarity of heterogeneity. In fact, the heterogeneity of both distributions seem to increase first and start to decline substantially later. The turnaround occurs earlier for the productivity distribution rather than for the output distribution.

For the remaining discussion in this subsection, we define two firm groups and assign all firms in each period to either of the groups by comparing the individual capital productivity with the current median productivity of the firm population. Panel (a) of Figure 3.9 shows the average productivity of these groups, the black line indicates the productivity of the high-tech group and the red line the productivity for low-tech firms. As one would expect, there is a substantial difference in terms of productivity. In addition, there exists a gap from the start indicating that the preceding pre-simulation has already generated a considerable heterogeneity of firms.¹¹ In order to detect whether or not there is technological catch up, we plot in panel (b) the relative productivity as a ratio between high- and low-tech firms. Apparently, the path of the relative productivity resembles Figure 3.8 (b), which has described the heterogeneity of firms' productivity. While the technological distance between less and more productive firms increases in the short run, we observe technological catch-up in the long term.

Panel (c) plots the average output for low- and high-tech firms. Evidently, there is a strong correlation between productivity and firm output so that high-productive firms account for significantly more output than low-productive firms. As in case of productivity, the pattern changes over time; in the short term high-tech firms grow at a high rate while the output of low-tech firms declines. As a result, a strong output divergence emerges during this phase (compare panel d showing the relative

¹¹Recall that the start state of this simulation is a snapshot of a simulation, whose start state was characterized by a homogeneous initialization for almost all variables.

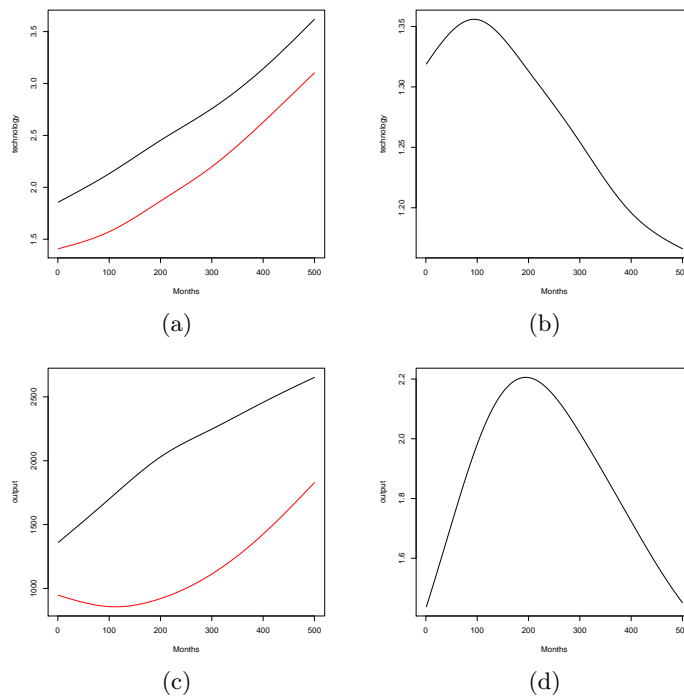


Figure 3.9: Upper row: Spline smoothed evolution of the capital productivity of high- and low-tech firms (a) and corresponding productivity ratio between high-tech and low-tech firms and output (b); lower row: Spline smoothed evolution of the output of high- and low-tech firms (c) and corresponding output ratio between high-tech and low-tech firms and output (d) .

output). Eventually, the growth of high-productive firms becomes less intense and, at the same time, the output of low-tech firms starts to grow at a high rate. Thus, a convergence of output can be observed in the long run, which is consistent with the long-term decline of the firm size heterogeneity.

The physical investment and the resulting evolution of capital stocks is closely linked with the output pattern (see Figure 3.10 a and b). During the period of output divergence, high-productive firms expand their capital stocks whereas investments of low-tech firms are below the depreciation so that their capital stocks decline. In the later phase, when output levels converge, we can also observe a convergence of capital stocks.

The vintage choice of firms is one of the important drivers of the evolution of capital productivity. The vintage choice is displayed in panel (c) and (d) of Figure 3.10, where panel (c) shows the average vintage choice per productivity group and panel (d) the relative vintage choice. Evidently, firms belonging to the group of high-productive firms systematically invest more in higher vintages than their low-productive competitors. In contrast to the gap for the capital productivity, there is no divergence of vintage choices at the beginning of the simulation; instead the productivity of the selected vintages converges from the start, where the convergence begins to cease at month 400.

When working with high-productive machines, an individual worker builds up specific skills faster if the worker is well educated, i.e. his general skill level b_h^{gen} is high (compare Section 3.2.3). For this reason, an important driver for the vintage choice is the educational attainment of the employed workforce. In the decision-

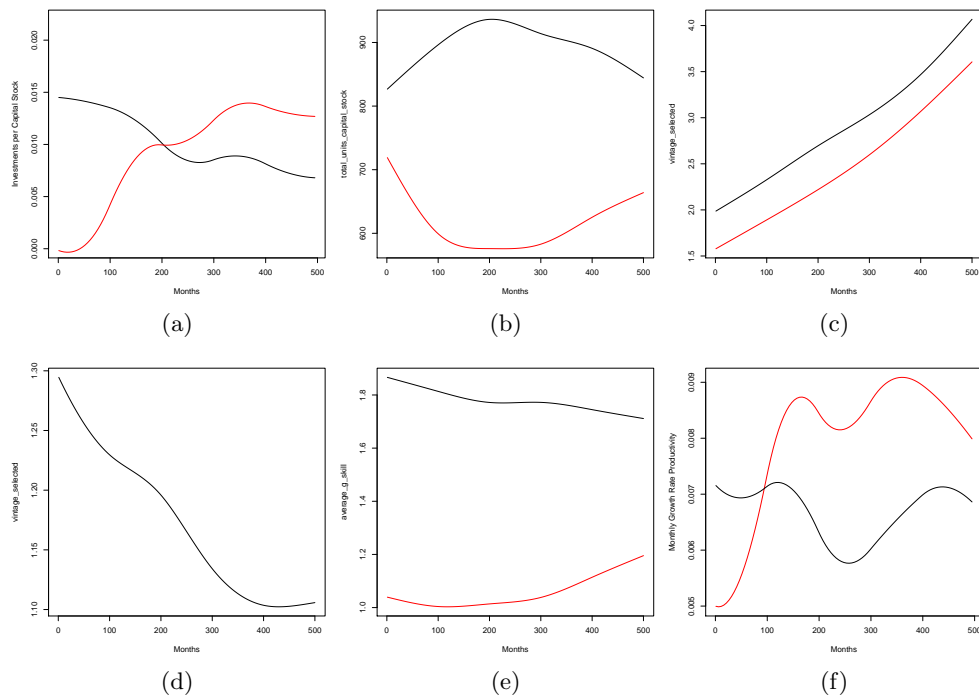


Figure 3.10: Spline smoothed evolution of investments (a), capital stocks (b), vintage choices (c) with the corresponding ratio high vs. low-tech firms (d), average general skills (d), and growth rates of productivity for low-tech (red line) and high-tech (black line) firms (f).

making regarding the vintage choice, the firm estimates the expected specific skill adjustment given the current average level of general skills of the incumbent workforce (see Section 3.2.4.3). If the firm has only a low-educated workforce, it will anticipate the only limited advantage of a high-productive vintage. In this case, the firm will invest in a less productive but cheaper one.

Panel (e) shows the average general skill level for the two firm groups. Apparently, there is a self-selection of workers according to their general skill groups so that high-productive firms attract mainly high-skilled workers. This self-selection might explain the persistence of productivity gaps between technological leaders and laggards. The preference of high-skilled workers to work for high-productive firms results in a general skill dispersion among the productivity level of firms. The polarized skill distribution, in turn, reinforces the spread of vintage choices. Moreover, panel (e) indicates that the gap in terms of general skills between high- and low-tech firms narrows over time. This convergence of general skills provides an explanation for the tendency of vintage choices to converge in the long run.

The quantitative investment decision and the vintage choice can explain the evolution of firms' heterogeneity in terms of productivity. While in the early stage of the simulation investments of low-productive firms are low, the high-productive firms intensively invest in their capital stocks. The purchased capital vintages are thereby more productive, which leads, as indicated in panel (f), to a temporarily higher growth rate of the productivity for high-tech firms. This translates in a technological divergence during this period.

On the other hand, the frontier grows steadily and from time to time the investment goods firm withdraws old vintages from the menu. Since the productivity

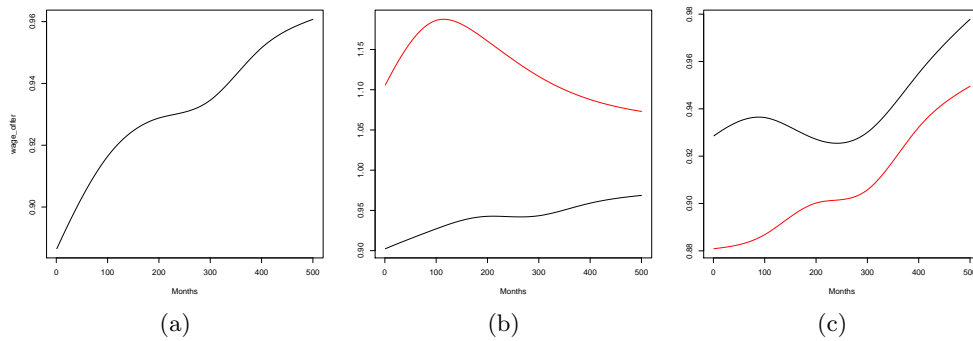


Figure 3.11: Spline smoothed ratios high-tech vs. low-tech firms for base wage offers (a), wage offer for high-skilled (red line) and low-skilled (black line) workers (b) and unit labor costs (red line) and unit production costs (black line) (c).

of the capital menu increases in total, also the vintages in which low-tech firms invest become more productive over time. Consequently, there is a gap between the productivity of the purchased capital and the productivity of their existing capital stock when low-tech firms start to intensify their investments. This gap is the reason why the average growth rate of low-tech firms' productivity starts to rise in the medium term and eventually exceeds the growth rate of high-productive firms. As time elapses, this process gradually merges with the declining productivity gap between high- and low-tech firms in terms of vintage choice and leads to the partial technological catch-up of low-tech firms.

In the following, we want to discuss the emerging general skill dynamics in more detail. As mentioned above, the general skill level of high-tech firms declines throughout the simulation, while for low-tech firms it first declines and later it starts to increase (see Figure 3.10 f). The dynamics of average skills is thereby a consequence of labor market activities of firms. In the initial phase when outputs diverge, high-tech firms expand their workforce while at the same time almost no high-skilled workers are available. As a result, these firms hire more low-skilled workers, which leads to a steady decline of their general skills. The average general skill level of low-tech firms, in contrast, declines during the first 100 months suggesting that in this phase there is a transfer of high-skilled workers from low to high-tech firms. At about month 100, there are almost no high-skilled employees working for low-tech firms. In the following, the average general skill level is constant at its lowest possible level for a longer period.

A critical factor for filling vacancies are wage offers that the firms post (see Section 3.2.6). Panel (a) of Figure 3.11 depicts the relative dynamics of base wage offers. At the outset, there is a considerable gap between the base wage offers of high- and low-tech firms, where the wage offers of low-tech firms are systematically higher. This gap narrows over time and is almost closed at the end of the simulation. The initial spread of base wage offers is caused by a systematical labor shortage of low-tech firms during the pre-simulation phase. A higher labor demand especially in the early stage of the main simulation prompts high-tech firms to increase their base wage offers, which leads to the observed convergence of base wage offers.

From the workers' perspective, it is not the base wage offer but the general skill specific wage offer that matters for the acceptance of a job offer. Panel (b) plots the (relative) wage offers for the low-skilled workers (black line) and high-skilled workers (red line). A comparison of the two lines shows a clear difference; wages for

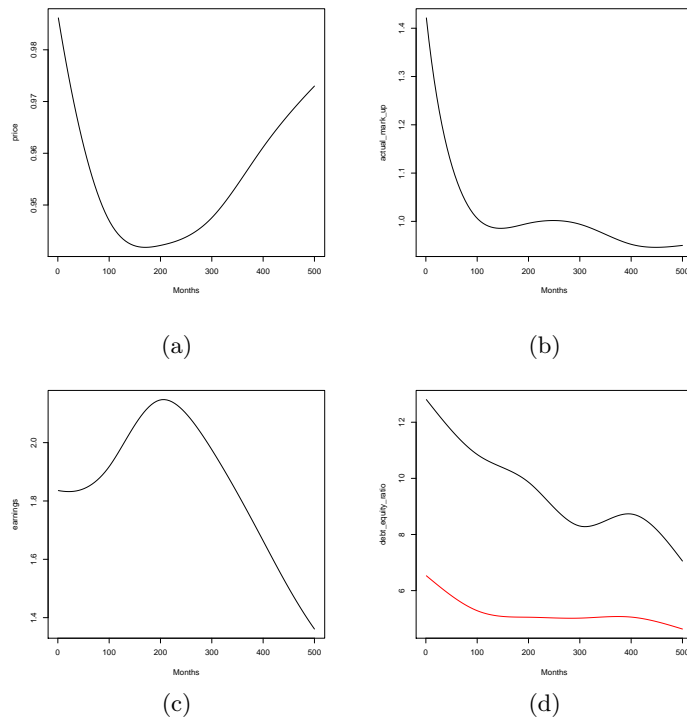


Figure 3.12: Spline smoothed ratios high vs. low-tech firms for prices (a), mark-ups (b), earnings (c); spline smoothed evolution of debt equity ratios (f) for high-tech (black line) and low-tech (red line) firms.

high-skilled workers are higher throughout the simulation if they are offered by high-tech firms. But the distance changes over time; initially the relative attractiveness of high-tech firms increases but later high-tech firms lose some of their leading position. Consequently, it becomes more attractive for high-skilled workers to accept job offers from low-tech firms. This leads to an increasing number of high-skilled workers employed by low-tech firms in the long run. In contrast, wage offers for low-skilled workers are higher for low-tech firms. The biggest difference can be observed at the beginning of the simulation and it becomes smaller as time elapses. Thus, it is initially less attractive for low-skilled workers to accept job offers made by high-productive firms. Since these firms have a high labor demand, they need to become more attractive for low-skilled workers, where this is achieved through a reduction of the gap to the wage offers for low-skilled workers posted by low-tech firms.

A consequence of rising base wage offers is that wages of high-tech firms grow disproportionately to their productivity so that labor becomes effectively more expensive. Since labor costs account for the biggest share of firms' total costs, higher unit labor costs will eventually affect unit production costs. This can be seen in panel (c) in which the red line shows (relative) unit labor costs and the black line (relative) unit production costs. Apparently, high-tech firms lose most of their cost advantages over the considered time horizon, which is one of the main drivers for the long-term convergence of output.

The dichotomy of the output evolution with a divergent phase in the short and convergence in the long run is accompanied by an corresponding change of relative prices (see Figure 3.12 a). During the output divergence, prices of low- and high-tech firms drift apart where high-tech firms, which aim at gaining additional market

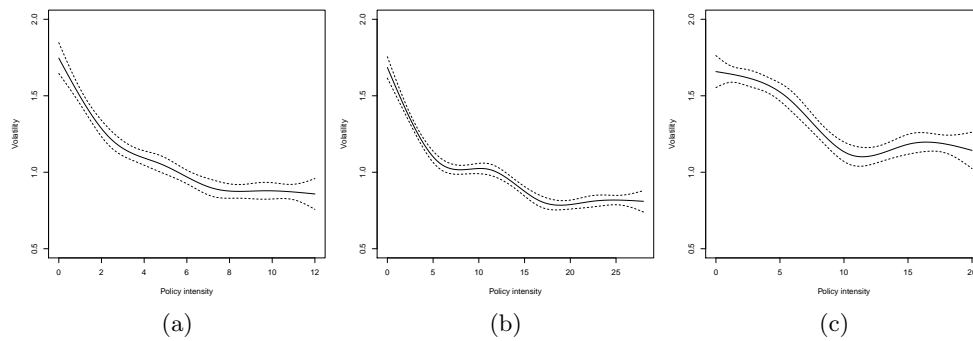


Figure 3.13: Effects of the consumption subsidy policy (a), investment subsidy policy (b), and technology subsidy policy (c) on the volatility of the business cycle.

shares, decrease their prices relative to the prices of their competitors. Conversely, when low-tech firms try to catch up in terms of output, they must close the price gap to the high-tech firms. Thus, the prices have to converge as well in the period of output convergence.

The initial divergence of prices and the simultaneous relative increase of unit costs of high-tech firms has a negative effect on the relative mark-ups (see panel b). While at the outset of the simulation, high-tech firms have considerably higher mark-ups, the lead melts away during the short period of strong price divergence and cannot be regained afterwards.

Looking at the relative profitability in panel (c) of Figure 3.12, one can see that high-tech firms generate higher profits throughout the simulation. Moreover, in the period until month 200, high-tech firms are able to even enhance the profitability compared to the low-tech firms. After month 200, profits of high- and low-tech firms converge. Altogether, the curve of relative earnings resembles the curve of relative outputs.

Finally, panel (d) shows the debt equity ratios indicating that high-tech firms are more indebted. By comparing the relative debts between the low- and high-tech firms (not shown here), one would see that for both measures there is again an initial divergence while later the debts of low- and high-tech firms converge.

3.4.3 Policy Effects on the Business Cycle Volatility

We now turn to the comparison of the three stabilization policies. One of the policy questions posed in Section 3.4.1 has been whether the policies are actually able to smooth the business cycle substantially. As already described in Section 3.3, an indicator for measuring business cycle volatility is the percentage standard deviation computed for the cyclical component of the time series total output from its HP filtered trend. For the baseline case, we have found an average volatility of 1.65%.

Figure 3.13 shows the effects of a variation of the policy intensity μ on this volatility measure.¹² The three panels demonstrate that each of the considered policies can reduce the business cycle volatility. In that sense, the policies are suitable to achieve the primary goal for which the policies have been designed. The effects show qualitatively similar patterns. The estimated curves that describe the relation

¹²The policy effects are estimated with means of a GAM where the business cycle volatility is the dependent and parameter μ is the explanatory variable. The dashed lines indicate the confidence intervals of the corresponding smooth term.

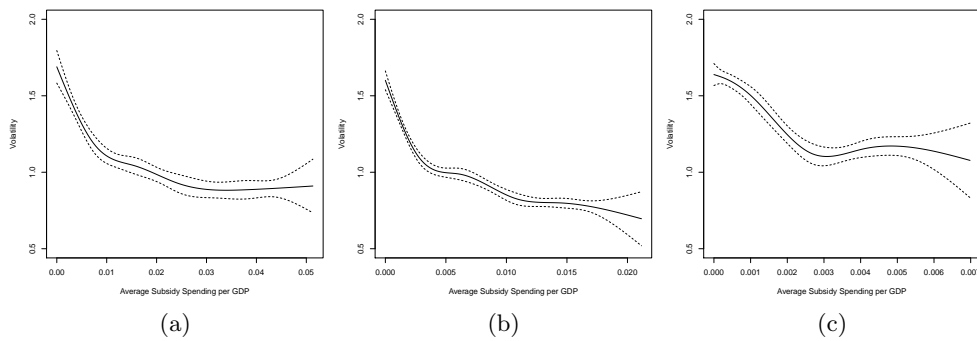


Figure 3.14: Estimated relation between business cycle volatility and policy expenditures per GDP (averaged over all periods) for the consumption subsidy policy (a), investment subsidy policy (b), and technology subsidy policy (c).

between volatility and the intensity of the policies are convex. Thus, the policies are characterized by diminishing returns with respect to the intensity parameter μ . Apparently, there seems to be a minimum level of volatility for each policy. The lower bounds are almost identical for the consumption and the investment subsidy policy but the minimum volatility of the technology policy is considerably higher.

It should be clear that a comparison of the policies based on Figure 3.13 cannot account for input efficiency. The reason is that the intensity parameter μ is used in different contexts such that equal values of μ are associated with different levels of additional government spending. To make the policies comparable in this respect, one can replace μ by an indicator measuring the average policy expenditures. In Figure 3.14 we show the re-estimated policy effects where we use the average monthly spending relative to the nominal GDP as input measure. Now one can see a clear difference in terms of input efficiency between the three policies. For obtaining the same volatility reduction, the government must spend a considerable larger share of the GDP for the demand stimulating policy than for the investment or technology stimulating policies. Overall, the technology policy seems to be the efficient one even if this policy does not lead to the same volatility reduction as the other two policies. A further observation is that in terms of fiscal spending the presumption of diminishing returns still holds. Altogether, these observations lead to the first qualitative insight:

Result 1: *All three policies lead to a substantial reduction of the business cycle volatility. However, the policies differ considerably in terms of their efficiency regarding the usage of fiscal resources. To obtain a similar volatility reduction, the government has to spend most funds for the consumption stimulating policy, while it has to spend considerably less for the investment and the least funds for the technology subsidizing policy.*

Besides the effectiveness to stabilize the business cycle, the policy analysis in this study tries to address possible long-term implications for other economic aggregates, where long-term effects on the growth path and the fiscal stability of the economy are of particular interest. In the following subsections, we will discuss the long-term implications and the mechanisms generating the implications in more detail starting with the consumption stimulating policy.

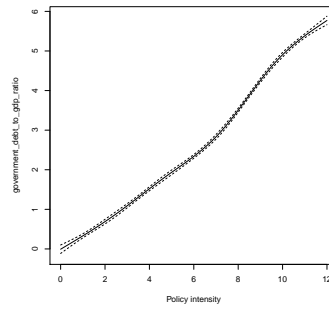


Figure 3.15: Effect of the consumption subsidy policy on the debt GDP ratio of the government measured at the end of the simulation.

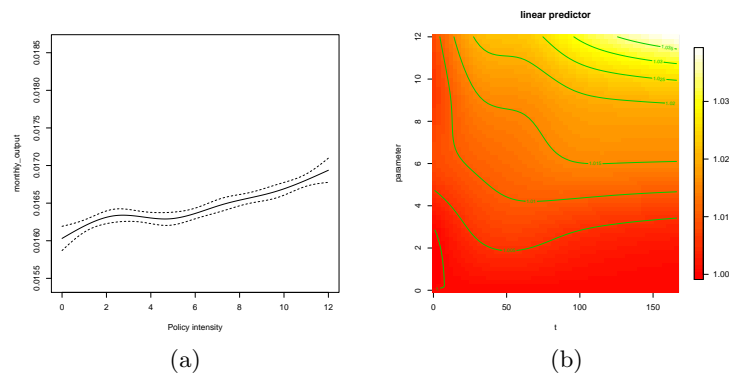


Figure 3.16: Policy effect on the average annual growth rate (left) and the evolution of the aggregated output (right).

3.4.4 The Consumption Stimulating Policy

As already discussed above, the business cycle smoothing with means of consumption stimulation is achieved at the expense of high fiscal payments. These subsidies are financed by budgetary resources and increase the expenditures of the government. This gives rise to the question which effect the policy might have on the government debt. Figure 3.15 depicts the estimated relationship between policy intensity μ and the public debt measured as the debt to GDP ratio at the end of the simulation. When the policy is not implemented (i.e. $\mu = 0$), the government budget is well balanced as there is almost no public debt for $\mu = 0$ after 500 months. The fiscally sound situation is superseded by an escalating indebtedness when the policy parameter is gradually increased. Evidently, the implementation and intensification of the policy forces the government to run fiscal deficits that accumulate to high levels of public debt. As a result, a smoothing of the business cycle by consumption subsidies can be associated with a lasting deterioration of the public debt situation.

But do these policy expenditures lead to a sustainable change of the long-term growth? In order to demonstrate the policy effect on long-term growth, we show in Figure 3.16 (a) the average annual real growth rate of the economy for the considered range of the policy intensity μ . Apparently, the policy effect on economic growth tends to be positive, where its strength increases with μ . Without policy, the average annual growth rate is about 1.6% and rises up to approximately 1.68% for $\mu = 12.0$. Note that the growth rate in panel (a) is averaged over the simulation horizon. Due to this time-based aggregation, one cannot obtain insights from panel (a) whether

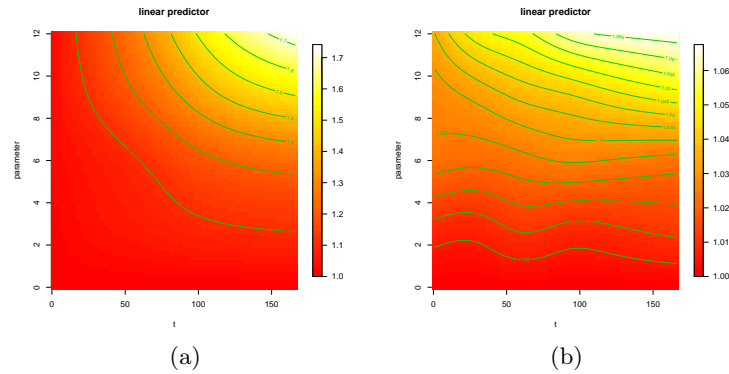


Figure 3.17: Policy effect on the nominal consumption budget (a) and the deflated consumption budget (b).

the policy generates a sustainable effect on the growth rate that shifts the economy at a higher growth trajectory. Otherwise the policy would only generate transient growth effects shifting the output trajectory.

To address the question of how the effects evolve over time, one has to study the effect of μ on the evolution of time series data. In this case, the policy effect is statistically co-explained by a second covariate, namely time t ; to account for both explanatory variables, we specify a new GAM, in which the smooth term jointly depends on t (in quarters) and μ . Technically speaking, since isotropic smooth terms of the sort of $s(t, \mu)$ are only good choices when covariates are on the same scale, which is not the case for μ and t , we opt for tensor product smooth terms to explain the joint effect of policy intensity and time (see Wood, 2006). The GAM is then described by

$$g = g_0 + te(t, \mu). \quad (3.50)$$

Panel (b) of Figure 3.16 displays the policy effect on the time series of aggregate output, where the effect is illustrated in terms of the relative deviation from the baseline case.¹³ The Spline model confirms the hypothesis of a positive growth effect of the policy but it also indicates that the change of the output premium is not constant over time. This observation seems to contradict the hypothesis of a possible uniform shift of the growth trajectory.

A more in-depth analysis of panel (b) reveals that the policy induces an initial growth boost which seems to be relatively independent from the policy intensity. At the outset, almost the same output increase can be achieved with low and high policy intensities (this is indicated by the almost vertical contour lines). As time elapses, this initial growth effect eases and the output gains become smaller, where under higher policy intensities the slow-down is less pronounced as under low intensities. Eventually, there is no further increase of the output premium for $\mu < 8.0$ (indicated by horizontal contour lines), whereas for higher policy intensities there still remains a growing output effect. The strongest impact on the aggregate output can be observed in the upper right corner of the predictor space at $t = 500$ and $\mu = 12.0$. In this area, the output is 3.6% higher than in the base scenario.

How does the policy lead to more output? The policy is a classical demand-oriented policy measure that aims at supporting the economy through a stimula-

¹³In the following, we illustrate the effects of the policy with means of heat maps in which the color code indicates the strength of the policy effect estimated from the Spline model with time (at x axis) and the intensity parameter μ (at y axis) as predictor variables.

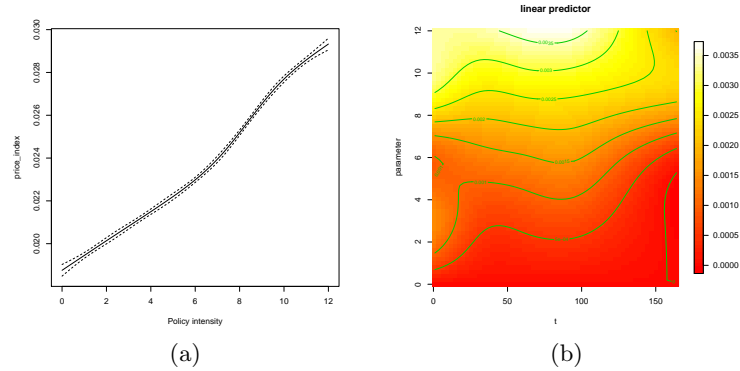


Figure 3.18: Policy effect on the average annual inflation rate (left) and the evolution of the change of quarterly inflation rates (right).

tion of private consumption. The higher consumption provokes firms to produce more output, which prevents the economy from sliding into recession. Panel (a) of Figure 3.17 shows the overall effect of the policy on the households' consumption budget, which is clearly positive; the premium increases steadily over time such that the consumption budget is much greater than in the base scenario at the end of the 500 months (e.g., for $\mu = 12.0$ the premium is about 70%). A comparison with the output effect reveals that the change of the consumption budget is several times stronger (e.g. about 20 times for $\mu = 12.0$).

It should be noted that panel (a) shows the nominal time series of consumption while the time series of total output is measured in real terms, i.e. a direct comparison is not meaningful. By adjusting for inflation, we can uncover the real policy effect on the consumption budget. In this case the consumption budget is valued at the same basis as real output, which makes a quantitative comparison appropriate. The change of the deflated consumption budget is displayed in panel (b). Again, the effect is positive throughout the simulation and becomes stronger as policy intensity increases. For lower intensities ($\mu < 6$), the policy seems to shift the real consumption level uniformly upward such that the relative distance to the base scenario is constant over time. For higher values of μ , the premium grows slightly with the consequence that the maximum increase can be observed in the upper right corner of the heat map.

If compared with its nominal counterpart, it turns out that the size of the deflated effect is much smaller (for $\mu = 12.0$, e.g., it is 6.5%). This suggests that the policy leads to a considerable increase of inflation (see below). At the same time, the effect on the deflated consumption budget is quantitatively stronger compared to the output effect. This in turn suggests that the policy generates more (real) demand as firms are actually able to satisfy (for $\mu = 12.0$, the difference between the premium of output and deflated consumption budget is 3.5% versus 6.5% at the end of the simulation).

The actual effect on the inflation is illustrated in Figure 3.18, in which we show the change of the average annual inflation rate in response to a change of μ (panel a) and the dynamics of the policy effect on the inflation rate over time (panel b, here we depict the effect on the quarterly inflation rate).¹⁴ As already suggested by the strong deviation of the deflated consumption budget from the nominal budget, there is a considerable increase of the inflation, where the effect seems to become stronger

¹⁴Note that in heat maps for variables denominated in rates such as growth rates, inflation, and unemployment rates, we show differences to the base scenario rather than relative deviations.

with increasing intensity μ .

We have assumed that firms are able to observe the nominal consumption budget which they take into account as a proxy for market size in their production planning. Hence, they realize when the nominal consumption budget has changed and adjust their strategies accordingly. There are basically two responses when firms observe an increased nominal demand, they can react by increasing the price or the output. Actually, they will implement a combination of both choosing that strategy which yields the highest expected gains given firms' expectations (compare Section 3.2.4.2). The observation of a positive effect on the deflated consumption budget suggests that firms try to serve at least some of the additional demand rather than inflating it completely. This conjecture is supported by the observation of increasing planned production quantities (see Figure 3.19 a). Apparently, firms adjust their production plans by increasing the intended output. But as there is a gap between the actual and the intended output, firms cannot fully realize the desired production plans.

In order to expand output, firms have to hire additional workers, for which they enter the labor market and post job vacancies. Panel (b) illustrates the positive effect of the policy on the total number of posted vacancies. A consequence of an increasing labor demand is that firms employ more workers and fewer households are unemployed. Accordingly, the consumption subsidizing policy is also conducive to reduce the unemployment in the economy (see panel c). The effect on the unemployment rate is, however, not uniform; while for lower levels of the policy intensity the (weak) impact on the unemployment seems to become slightly more intense over time, the pattern is different for high values of μ . In this case the effect becomes stronger until approximately quarter 90 and subsides afterwards. This pattern mirrors the evolution of the unemployment rate in the base scenario, which has its maximum at around quarter 90 (compare Figure 3.7 on page 103). A high unemployment rate is associated with a lower labor market tension so that the potential for a reduction of the unemployment rate is high during this period.

A decreased unemployment rate reduces the pool of job seeking workers such that firms are confronted with a situation in which they can fill less of their open job vacancies. The additional rationing on the labor market is illustrated in panel (d), which shows the effect on the fraction of posted vacancies remaining unfilled at the end of the recruitment process. Obviously, the effect resembles that of the unemployment rate such that the effect is the strongest when the largest reduction of the unemployment rate can be achieved.

The emerging labor shortages can to some extent explain the gap between intended and actual output. Besides the output gap, another consequence of a higher labor market tension is a fierce competition for workers in which firms are forced to gradually increase their wage offers to attract job seekers for their vacant jobs. This higher competition at the labor market causes wage increases that are disconnected from the productivity growth in the economy. Eventually, the input factor labor becomes more expensive translating into higher unit labor costs. Panel (e) depicts the change of the growth rate of unit labor costs, thereby indicating that labor costs grow faster under the policy.

The increasing labor costs can explain why the increase of the consumption budget is nominally much stronger than in real terms. The labor income is the main contribution to households' total income and, therefore, it is the prime determinant of the nominal consumption. Thus, growing wages lead to increasing nominal consumption budgets but at the same time they cause rising production costs. These costs are mainly translated into higher prices with the consequence that, in the

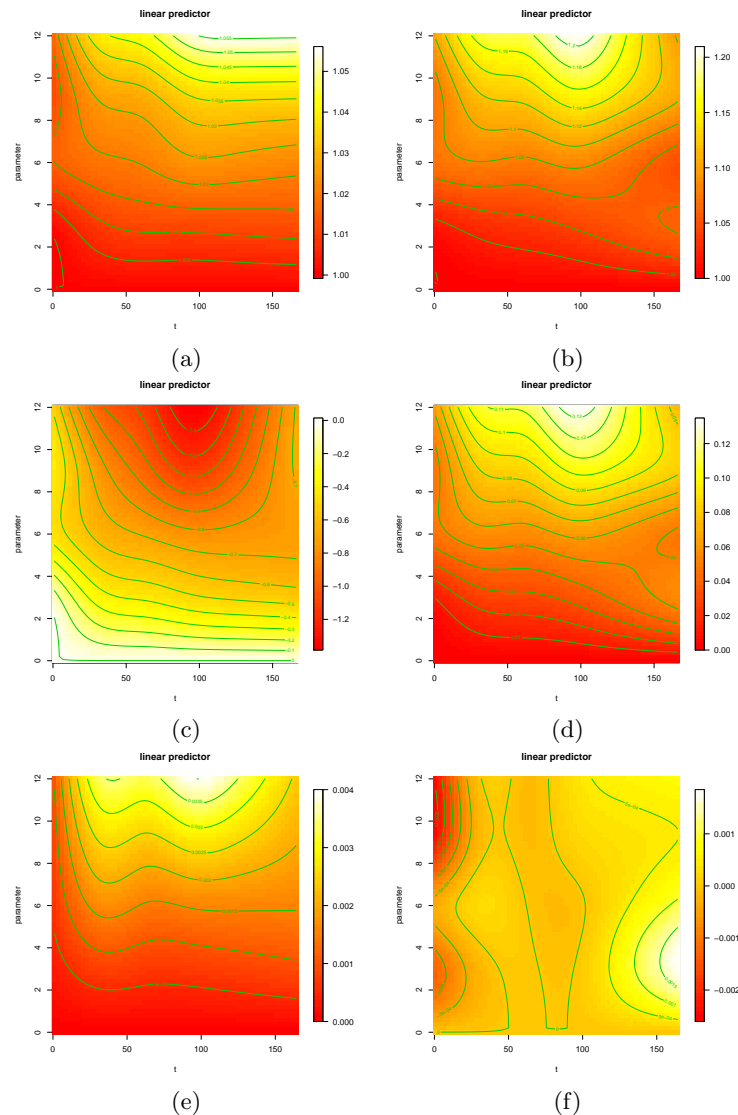


Figure 3.19: Policy effect on planned output of firms (a), number of posted vacancies (b), unemployment rate (c), share of posted vacancies remaining unfilled (d), quarterly growth rate of labor unit costs (e) and quarterly growth rate of deflated labor unit costs (f).

end, the nominal wage increase is not associated with more real purchasing power. Panel (f) shows the policy dynamics of the growth rate of real unit labor costs. Except for a short period at the outset and for the last period at lower policy intensities, the change of the real growth rate is almost null such that the growth of nominal labor costs is largely offset by inflation. This suggests that, indeed, rising labor costs are the main driver of additional inflation.

We now come back to the discussion of the policy effects on the unemployment rate. In panel (c) of Figure 3.19, we have observed that for high policy intensities there is a strong decline of the positive employment effect in the last phase of the simulation. Even though the number of additionally employed workers declines relative to the base scenario, we cannot observe a simultaneous reduction of the output premium in Figure 3.16 (b). To make this possible, there must be an increase of productivity in the economy such that firms can produce more output with less input

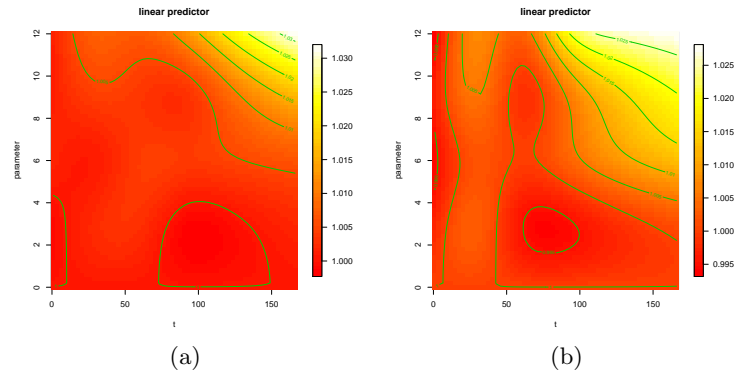


Figure 3.20: Policy effect on the average productivity of the used capital stock (a) and the average vintage choice (b).

factors. This positive effect on productivity is indicated in panel (a) of Figure 3.20, where this figure shows the average quality of the productive capital productivity measure. Apparently, there is no effect on the technology except for the last phase of the simulation. The positive effect on the technology coincides with the declining employment effect. Moreover, it coincides with the positive effect on the output growth for high policy intensities in the last phase of the simulation. Panel (b) indicates that the improved capital productivity is the result of firms' decision to invest in more productive vintages of the capital good. Since the evolution of the frontier is identical regardless the intensity of the policy, this suggests a faster diffusion of new technologies.

Putting all the observed implications together, we can summarize the effectiveness of the consumption subsidizing policy in the following qualitative insight:

Result 2: *The consumption subsidizing policy has an amplifying effect on the long-term growth in the economy and leads to more employment. At the same time, the policy induces more inflation and increases the government debt substantially. In the long run, the positive growth effect for high policy intensities is technology-driven by a faster diffusion of new technologies.*

So far, the analysis of the consumption policy has been focused on aggregated time series. But Section 3.4.2 has revealed that firms are characterized by a considerable degree of heterogeneity with respect to output and technological productivity. Even without the policy intervention, the economy undergoes dynamical changes of firms' heterogeneity so that the interaction of the policy and the heterogeneity of firms might also be worth considering. Figure 3.21 shows the policy effect on firms' heterogeneity with respect to output (panel a) and technology (panel b). Both panels show a similar picture, namely that the policy effect on heterogeneity varies over time, where three distinct phases can be identified. At the outset, the effects on the heterogeneity of output and technology are both slightly positive, which coincides with the initial increase of firms' heterogeneity of technology and output in the base scenario (compare Figure 3.8 on page 104). In the medium term, these positive effects turn into negative ones, where the effect on the technology heterogeneity seems to lead the other effect. In the long run one can, at least for higher policy intensities, observe a strong increase for both types of heterogeneity. For lower intensities, there is only a small increase of the output heterogeneity, whereas the technological heterogeneity keeps its gap to the base scenario.

The observation that the policy influences the heterogeneity within the firm

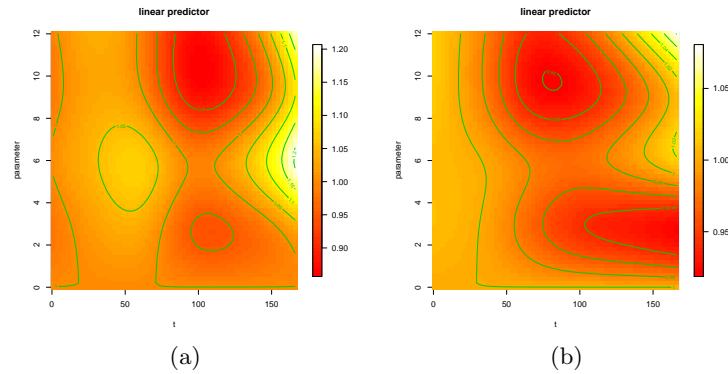


Figure 3.21: Policy effect on the percentage standard deviation of firms' output (a) and productivity (b)

population suggests that there are systematic differences in firms' response to the consumption subsidizing policy. In the discussion of the base scenario, we have demonstrated that there are different dynamics of firms with a high-productive capital stock (high-tech firms) and those with a low-productive capital stock (low-tech firms).¹⁵ In the following, we analyze whether there are systematic differences in the policy effects on the behavior of high- and low-tech firms.

In the upper panels of Figure 3.22, we display the policy effect on output of high-tech (panel a) and low-tech firms (panel b). The panels show that, indeed, low- and high-tech firms respond differently, where the responses vary over time and evolve systematically in opposite directions. We can basically identify three distinct phases. In the short term, high-tech firms expand their production while at the same time the output of low-tech firms slightly declines. This leads to an overall increase of the heterogeneity as high-tech firms produce on average more output than low-tech firms. As time elapses, the positive effect on the output of high-tech firms ceases and becomes negative, while at the same time low-tech firms increase their output substantially. This leads to a reduction of the output heterogeneity of firms in the medium term. And finally, the effect on high-tech firms increases again in the long run and the effect on low-tech firms declines, which is also consistent with the positive effect on the heterogeneity in the long term. Qualitatively, the same pattern can be observed for the policy effect on investments of high (panel c) and low-tech firms (panel d).

How can the different behavior of low- and high-tech firms be explained? To understand the underlying mechanism, we first focus on what happens in the short term. The reason why high-tech firms benefit almost exclusively from the policy in the short run is that these firms start with a competitive advantage. At the outset, high-tech firms have (by definition) a higher technological productivity but also a superior human capital endowment. Both translate into cost advantages that allow high-tech firms to set lower prices without impairing the price costs margin substantially. This competitive advantage in turn gives high-tech firms scope to respond more aggressively on the additional demand generated by the policy. Thus, when the policy is introduced, high-tech firms make use of their higher competitiveness and grab most of the emerging demand.

The initial output expansion of high-tech firms comes along with a relative increase of labor demand towards high-tech firms. This is illustrated in panel (a) of

¹⁵High-tech firms in period t are those firms whose productivity is above the median productivity in t . Accordingly, low-tech firms are those firms with productivity below the median.

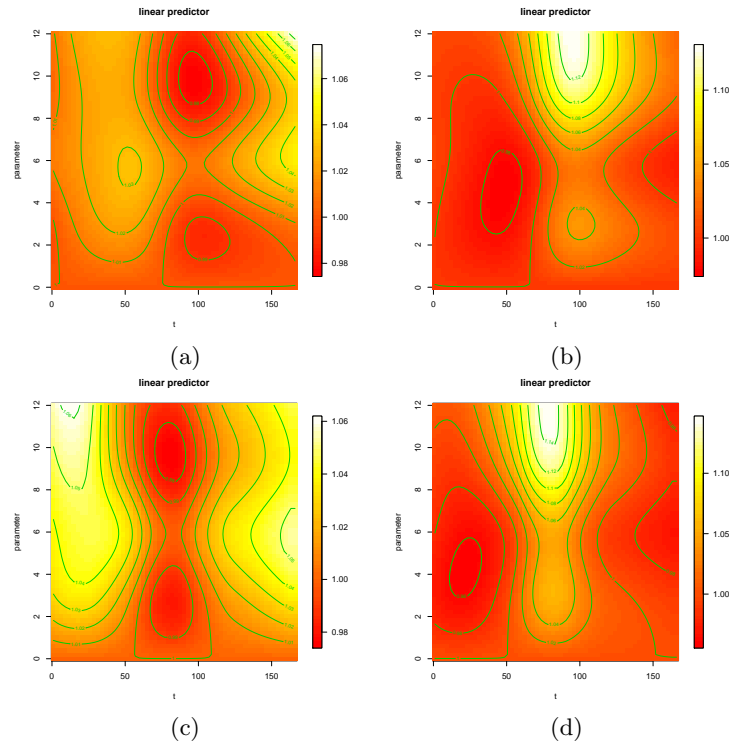


Figure 3.22: Upper row: policy effect on the output level of high-tech (a) and low-tech firms (b); lower row: policy effect on the investment level of high-tech (c) and low-tech firms (d);

Figure 3.23, which shows the policy effect on the ratio of the number of posted vacancies between high- and low-tech firms. As this ratio is shifted up in the short run, high-tech firms account for a larger share of the additional job offers.

The relative labor demand has a positive effect on the size of high-tech firms' workforce and the overall employment. At the same time, a higher employment intensifies the competition on the labor market, which in turn influences the dynamics of wage offers. This competitive pressure is mostly fueled by two phenomena of the base scenario; first, high- and low-tech firms differ in their relative attractiveness for workers with different general skills, where high-tech firms offer competitive wages only for high-skilled workers (compare Figure 3.11 on page 107). And second, there are almost no high-skilled workers available in the early phase of the simulation, where high-skilled workers are almost exclusively employed by high-tech firms. As a consequence, high-tech firms must aim at attracting low-skill workers for open job positions. Since the wage offers for low-skill workers are not competitive in this period, high-tech firms have to adjust their wage offers by increasing the base wage offer (Figure 3.23 b). Panel (c) indicates the effect on the relative wage offer for low-skill workers between high- and low-tech firms. It illustrates that high-tech firms become relatively more attractive for low-skill workers. This explains why high-tech firms succeed in increasing the number of workers and eventually in increasing the production quantities during this phase. There is also an effect on the wage offers for high-skilled workers (panel d), where the policy leads to a slightly faster divergence between high- and low-tech firms.

Increasing base wage offers are associated with increasing wages that firms have to pay to their employees. These wage increases are cost-relevant as they are dis-

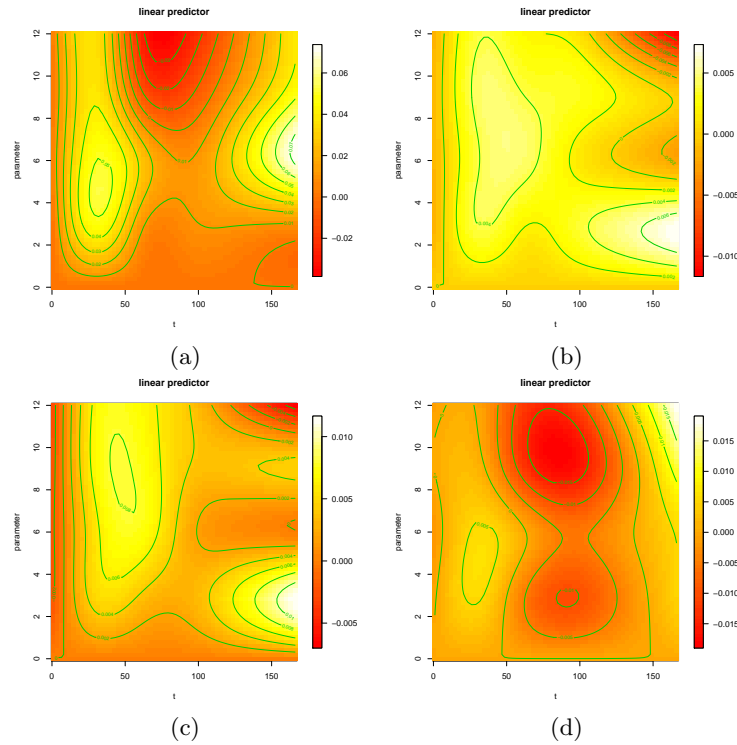


Figure 3.23: Policy induced change of the ratio of posted vacancies (a), base wage offers (b), wage offers for low-skilled workers (c) and wage offers for high-skilled workers (d) between high- and low-tech firms.

connected from the productivity growth and, therefore, result in higher unit (labor) costs. As described above, base wage offers between high- and low-tech firms are shifted towards high-tech firms with the consequence that high-tech firms lose some of their cost advantages (see Figure 3.24 a). At the same time, high-tech firms set prices more aggressively in order to expand and sell the additionally produced output. As a consequence, mark-ups on labor costs (the price divided by unit labor cost) of low-tech firms grow faster than those for high-tech firms in the short term (see panel b showing the differences between the policy induced change of the growth rates of mark-ups for high- and low-tech firms). The converging mark-ups indicate that high-tech firms forfeit some of their relative profitability and competitiveness over this period. At the same time, high-tech firms expand their workforce. As the labor potential of high-skilled workers is almost depleted at this time, most of the new hires are low-skilled workers. This in turn lowers the average general skill level of high-tech firms (see panel c), which might additionally contribute to a reduction of the competitive advantage of high-tech firms. Altogether, the observed phenomena reduce the competitive pressure on low-tech firms and enable them to choose a more aggressive competitive strategy. This allows them to lower the relative prices and to start expanding their output. As a consequence, we observe the transition to a medium-term state of the economy, in which low-tech firms expand relative to the base scenario, whereas high-tech firms lower their output.

The shift of the relative output towards low-tech firms in the medium run is associated with an increasing effect on the number of posted vacancies of low-tech firms. Consequently, the strength of the relative effect on posted vacancies in Figure 3.23 (a) diminishes, where for higher values of μ the effect becomes even negative.

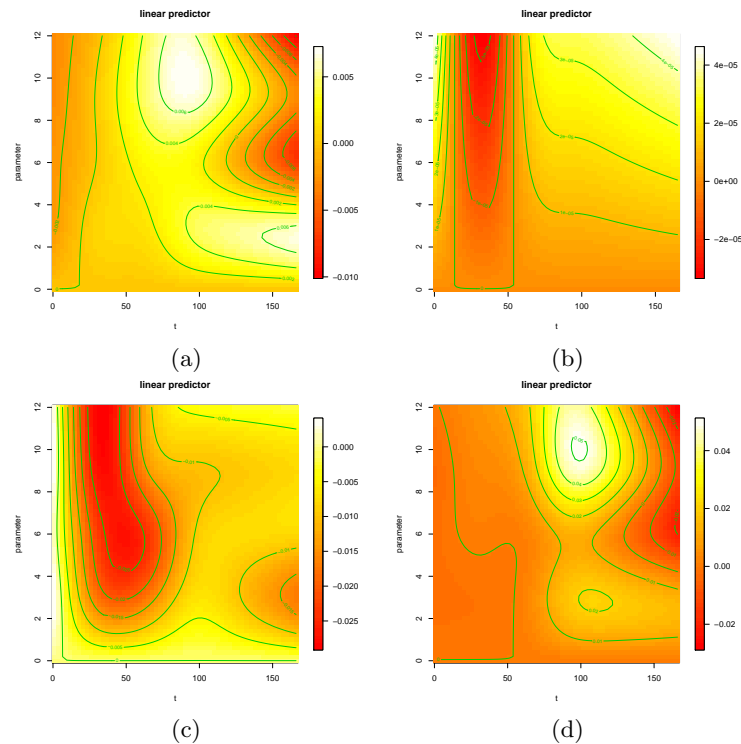


Figure 3.24: Upper row: policy induced change of the ratio of unit labor costs (a) and the growth rate of mark-ups on unit labor costs (b) between high- and low-tech firms; lower row: policy effect on the general skill level of high-tech (c) and low-tech firms (d).

Regarding the wage offers, there are almost no changes in the effects for the base wage offers and also no effects on the relative wage offers for low-skilled workers. But the gap in terms of wage offers for high-skilled workers becomes closer. Thus, the policy amplifies the convergence of wage offers for this skill group with the result that low-tech firms can increase their relative attractiveness for high-skill workers in this phase. The improved attractiveness has a positive effect on the average general skill level of low-tech firms (see Figure 3.24 d). The positive effect on the wage offer for high-skill workers can thereby be explained by a growing capital productivity in this period. The increasing productivity arises because low-tech firms intensify the capital investments relative to the base scenario (see Figure 3.22 d). This leads to a proportionately higher share of newer and more productive vintages in the capital stock, which increases the average capital productivity.

Figure 3.19 on page 115 has shown that the policy has its strongest impact on the labor market tension in the medium term. The effect on the unemployment rate and the number of posted vacancies is the strongest in this period, while the ratio of vacancies that remain unfilled also reaches a peak. At the same time, the observed dynamics of wage offers in the medium term imply that first, high-tech firms cannot enhance their relative attractiveness for low-skill workers, which means that low-tech firms are still more attractive, and second, low-tech firms become more attractive for high-skill workers. Thus, high-tech firms are increasingly facing the problem of labor shortages. This can be seen in panel (a) of Figure 3.25, which shows the relative effect on the fraction of unfilled vacancies. Apparently, the fraction of vacancies remaining open after the hiring procedure in the medium run increases more for

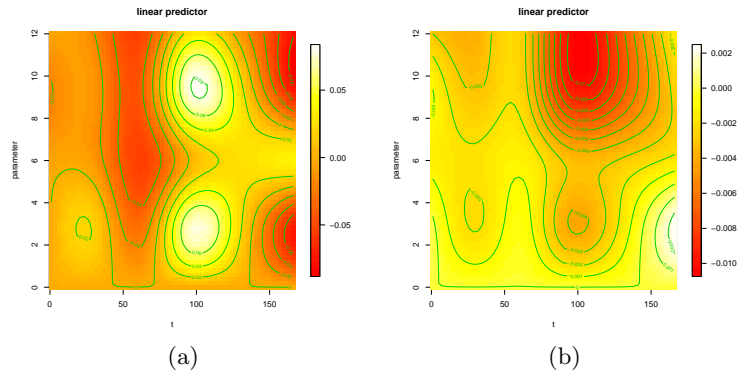


Figure 3.25: Policy induced change of the ratio of unfilled vacancies (a) and production rate (b) between high- and low-tech firms.

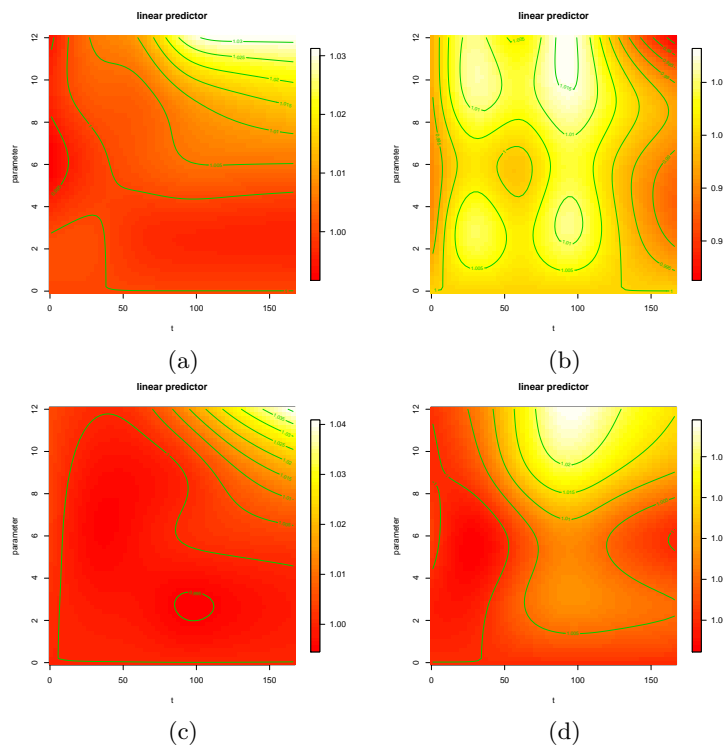


Figure 3.26: Upper row: policy effect on the vintage choice of high (a) and low-tech firms (b); lower row: policy effect on the average capital productivity of high (c) and low-tech firms (d).

high-tech firms than for low-tech firms. Because these firms are more rationed at the labor market, the lack of workers has a corresponding effect on the production rate (the ratio between actual and planned output). Indeed, as panel (b) indicates, the proportion of actually produced output declines more for high-tech firms, where the effect is the strongest for high policy intensities.

Besides employing more of the input factors capital and labor, there is also another way of expanding the production quantity, namely by renewing the capital stock through a replacement of old and less productive machines with newer and more productive ones. This strategy of investing in more productive technologies is pursued by high-tech firms in response to the labor shortage in the medium term. This can be seen in Figure 3.26 (a), which shows the policy effect on the vintage

choice of high-tech firms. Apparently, under higher policy intensities, when the effect on the output gap is the strongest, high-tech firms substitute the scarce factor labor by investments in the more productive vintages of the technology. As a result, the capital stock and, eventually, through the learning-by-doing process, also the workers become more productive so that altogether the production capacity of high-tech firms increases in the long term (see panel c for the capital productivity). The enhanced productivity leads to the long-term increase of output of high-tech firms and at the same time to a declined labor market tension.

For low-tech firms, there is only a small positive effect on the vintage choice (Figure 3.26 b). This effect can mostly be explained by the positive effect on the average general skill level for high policy intensities during the medium term. Accordingly, the positive effect on the vintage choice becomes smaller in the long term when also the effect on the general skill level declines. The positive effect on the average productivity of the capital stock for low-tech firms (panel d) is driven not only by the vintage choice but also by investment effects. Intensified investments lead to a higher share of new and more productive vintages in the capital stock of low-tech firms.

Consequently, the increasing heterogeneity that we have observed in Figure 3.21 for firm sizes and productivity in the long run is due to an emerging competitive advantage of high-tech firms that is triggered by reactions of high-tech firms on a strongly increased labor market tension in the medium term. This advantage enables them to gain and expand a leading position in the competition. Altogether, we can summarize the obtained insights regarding the policy effects on the evolution of firms' heterogeneity in the following result:

Result 3: *The effect of the consumption stimulating policy on the heterogeneity of firms is not uniform over time. While the policy leads to more heterogeneity in the short and in the long run, it has a heterogeneity reducing effect in the medium run. This observation is mostly driven by different short-term adjustments of output strategies of high- and low-tech firms and their corresponding adjustments of labor demand in response to the implementation of the policy. The adapted labor demand triggers medium- and long-term dynamics that alter the wage and cost structure in the economy and result in the observed evolution of heterogeneity. For high policy intensities, the induced dynamics at the labor market prompt high-tech firms to substitute labor with more productive technologies in the long run. This substitution improves the productivity of high-tech firms and generates additional output.*

3.4.5 The Investment Subsidy Policy

Quite a different picture emerges compared to our discussion in the previous subsection, if we consider the implications of the investment subsidizing policy. Under this policy, a firm receives a public subsidy when it invests in physical capital. The size of this subsidy depends on the intensity of the policy μ and the deviation of the quarterly growth rate from the threshold value g^{th} . When deciding about investments, it is assumed that firms take this subsidy into account.

Figure 3.14 on page 110 has indicated that the investment subsidizing policy can achieve the same reduction of the business cycle volatility as the consumption policy but with less financial resources. As pointed out in the discussion above, a criticism regarding the consumption subsidizing policy has been its strong negative effect on the public debt. If the investment policy is associated with less government spending, it should also have a less pronounced negative effect on the public debt. Indeed, as

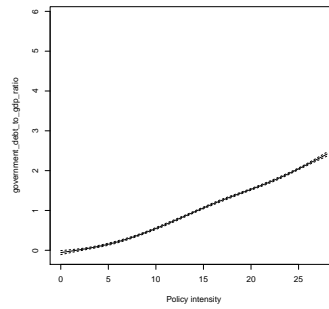


Figure 3.27: Policy effect of the investment subsidizing policy on the public debt measured as debt to GDP ratio at months 500.

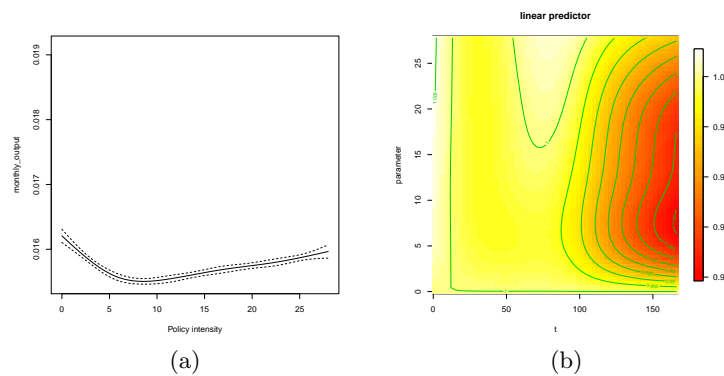


Figure 3.28: Spline-smoothed policy effects of the investment subsidizing policy on quarterly growth rates of output (a) and the evolution of aggregated output.

Figure 3.27 indicates, the business cycle smoothing by subsidizing investments in the consumption goods sector leads to a higher public debt at the end of the considered time horizon but the increase of the debt GDP ratio is less pronounced as for the consumption policy (compare Figure 3.15 on page 111). As a consequence, the investment subsidizing policy seems to be fiscally superior.

If we compare the real effects of the investment policy, the observation becomes more ambiguous. Figure 3.28 (a) shows the relationship of the average annual growth rate and the policy intensity represented by parameter μ . The investment policy has a negative effect on the long-term growth rate. Thus, the policy has the opposite effect to the consumption subsidizing policy. Furthermore, while the growth effect of the consumption stimulating policy increases monotonically in μ , the average growth rate is first decreasing in μ but later the growth rate recovers and reaches almost its initial level. Thus, the function representing the Spline-smoothed regression of the relation between the policy intensity and the average annual growth rate is U-shaped. Thereby, the policy has its strongest impact for moderate levels of μ (between 5 and 15).

More information concerning the policy effect on the GDP provides panel (b), in which we display the emerging dynamics of the policy effect on the aggregate output trajectory measured relative to the base scenario. This panel indicates that the policy generates not only a non-monotonic impact on the average growth rate but also highly non-linear effects on the output trajectory. While there is virtually no effect in the first two-thirds of the encompassed time, one can observe the emergence of a negative output effect in the last third of the simulation. The strongest output

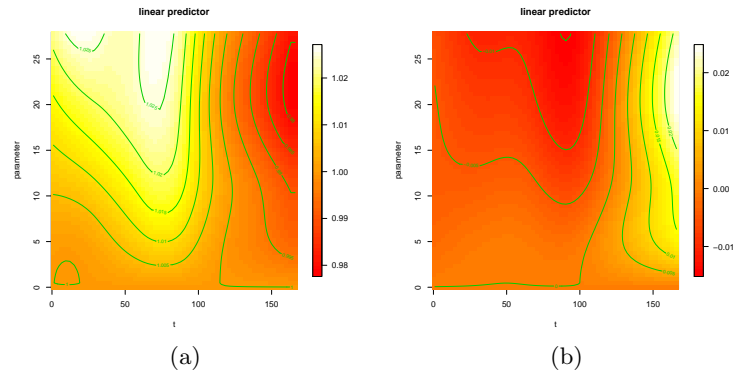


Figure 3.29: Policy effect on investments (a) and capacity utilization (b).

reduction is obtained at intensities between 5 and 15, which is exactly the same range in which the average growth rate has its minimum. Likewise, the observation of an easing output effect for high values of μ is consistent with the U-shaped relation reported in panel (a). It is in any case worth noting that the emergence of a negative policy effect depends not only on the intensity of the policy itself but also on the considered time horizon.

It is the direct effect of the subsidy to lower the price of capital goods. But does the investment policy encourage firms to invest more in their physical capital stocks? Panel (a) of Figure 3.29 depicts the policy effect on the investment level relative to the base scenario. It indicates that firms initially intensify their investments in response to the policy and build up more production capacity. But the investment level is not permanently above the level of the base scenario. When the output declines relative to the base scenario in the long term, firms adjust their investments accordingly. Furthermore, the additional production capacity built up in the short and medium term is not fully translated into more output. This can be seen in panel (b), which indicates a lower capacity utilization of firms' capital stock in this period.

Figure 3.30 (a) illustrates that higher investments are not the result of a deliberate decision of firms to substantially increase the output in the aggregate. By showing the policy effect on the planned output, it becomes apparent that the effect on planned output resembles the effect on actual output. In the short and medium term the policy does not lead to an appreciable increase of the planned output, whereas in the long term the planned output declines relative to the base scenario. There are, however, small differences between the policy effect on the planned and the actual output. These differences can be highlighted by considering the policy effect on the production rate, i.e. the ratio between the actual and planned output (see Figure 3.30 b). In the phase of higher investments, there is a negative effect on the production rate, which means that the gap between actual and intended output increases. This suggests a certain level of rationing that firms experience in this period.

In the lower row of Figure 3.30 we show the policy effect on the nominal (panel c) and deflated consumption budget (panel d). Similarly to the consumption subsidizing policy, the policy has a positive effect on the nominal consumption budget throughout the simulation. The strength of the effect also grows over time but, compared to the consumption policy, the growth is less pronounced (the premium is at most 22% after 500 months compared to about 70% for the consumption policy). Furthermore, the policy effect on the deflated consumption budget is positive in the

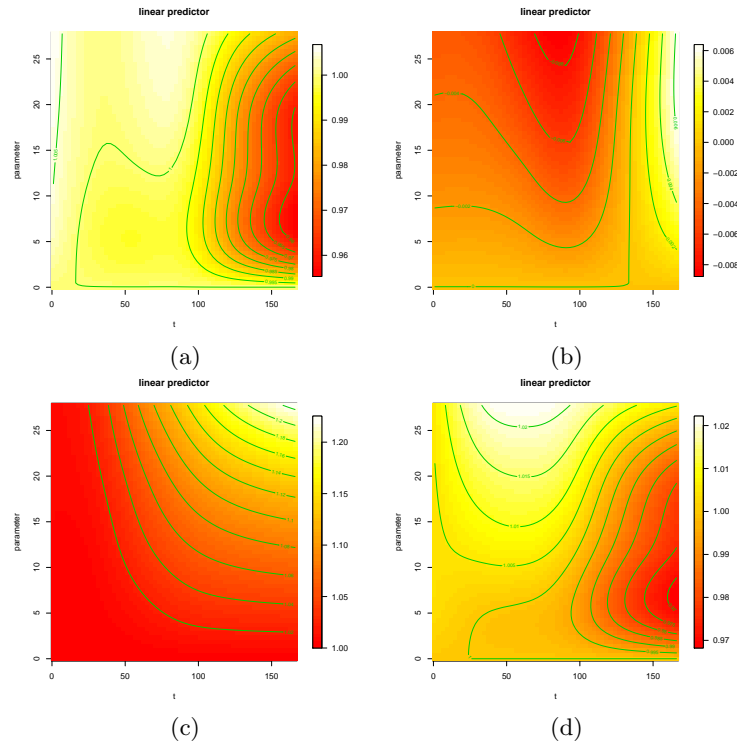


Figure 3.30: Policy effect on the aggregated level of planned output (a), production rate (b), nominal (c) and deflated consumption budget (d).

short and medium term but becomes negative in the long term. Thus, it shows similarities to the policy effects on planned and actual output. It is worth mentioning that in the short and medium term the effect on the planned output is almost null despite the fact that the policy has a clearly positive effect on real market demand in this period.

The differing evolution of nominal and real consumption budget is thereby consistent with the effect on the inflation rate (see Figure 3.31). The average annual inflation rate is increasing with the policy intensity (see panel a) but the impact of the policy is less pronounced compared to the consumption subsidizing policy. For the highest policy intensity, one obtains an average annual inflation of 2.2%, while for the highest intensity of the consumption policy the maximum inflation becomes 3.0% p.a. Panel (b) shows that the strength of the effect on the (quarterly) inflation rate changes over time, where most of the inflation is generated in the last phase of the simulation. Apparently, the negative real effects on output and demand are caused by an increasing inflation, when firms decide to increase their prices more rapidly rather than to expand the production.

As already pointed out in the discussion of the consumption stimulating policy, production costs are an important driver of inflation. When there are increasing costs, firms will pass on most of the additionally arising costs to the price in order to maintain their price cost margins. Panel (a) of Figure 3.32 shows the policy induced change of the growth rates of unit labor costs. For the short and medium term, the deviation of growth rates seems to be consistent with the policy effect on the quarterly inflation rates, where the labor costs grow slightly faster than the price index. In the long term, this link is obviously not present any more and the policy effects on inflation and on the growth of labor evolve in different directions.

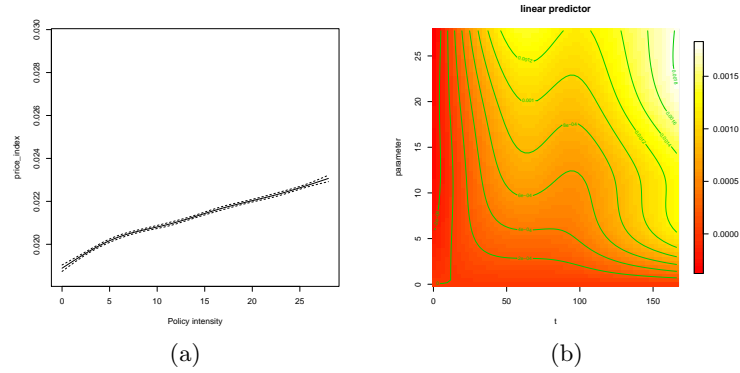


Figure 3.31: Policy effect on the average annual inflation rate (left) and the evolution of the change in the quarterly inflation rates (right).

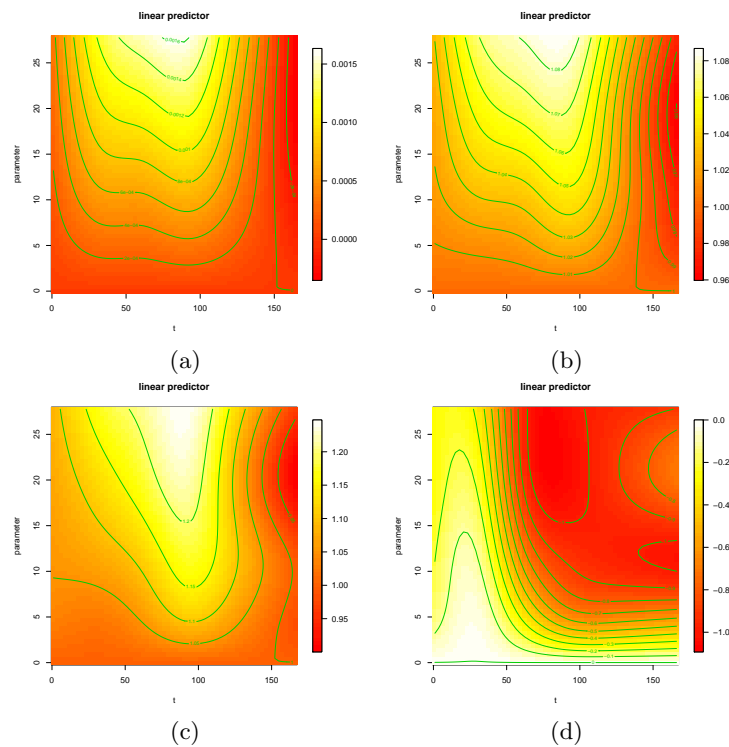


Figure 3.32: Policy induced change of the growth rate of unit labor costs (a); policy effect on the number of posted vacancies (b), the share of posted vacancies that remains unfilled (c); policy induced change of the unemployment rate (d).

Panel (b) depicts the policy effect on the number of posted vacancies. As this effect resembles the effect on the growth rate of labor costs qualitatively, one can conclude that also in this policy scenario the effect on the growth of unit labor costs is mostly driven by the change in the labor demand of firms. Compared to the baseline scenario, the number of posted vacancies increases in the short and medium term and declines in the long run. At the same time, the number of unfilled vacancies shows a qualitatively similar pattern (panel c). The strongest impact on the number of unfilled vacancies in the medium term coincides with the effect on the output gap (compare Figure 3.30 b). Thus, the (slightly) increasing output gap seems to be a consequence of a lack of workers.

The positive effect on the labor demand can also explain why the nominal con-

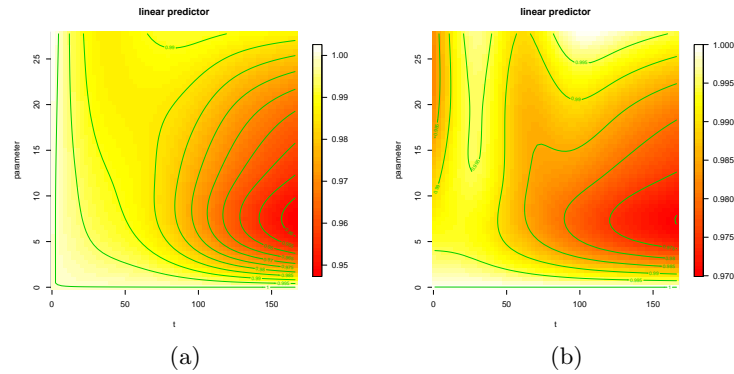


Figure 3.33: Policy effect on the average productivity of the capital stock (a) and the average vintage choice of investing firms (b).

sumption budget is increasing with the policy. Through the higher labor demand, the policy leads to an increase of nominal wages with the consequence that households can spend more money for consumption. A further contribution to the growth of the nominal consumption budget arises indirectly through the subsidies. As discussed above, the subsidies are investment-enforcing in the short and medium term and, therefore, increase the revenues of the investment goods producer. These revenues are paid out as dividends and end up in the payment account of households.

The increased labor demand has also an effect on the unemployment rate of the economy (see Figure 3.32 d), where as a general rule the policy is employment-promoting. For fixed levels of the policy intensity, the effect on the unemployment rate seems to pass two plateaus; while in the short run there is almost no effect, the unemployment rate is shifted down by about one percentage point within a few quarters in the medium term. In the long run the unemployment rate keeps the difference to the baseline case despite some minor ups and downs. The maximum reduction of about one percentage point is already reached at a low intensity of about $\mu = 5.0$. Altogether, the policy effect on the unemployment differs from the pattern that has been observed for output and investments.

The reason why the policy does not cause a positive output effect despite the observation of a positive employment effect in the medium and long term can be seen in Figure 3.33. In this figure, we show the policy effect on the capital productivity (panel a) and the vintage choice of investing firms (panel b). Panel (a) shows that from the beginning the productivity of the capital stock declines compared to the base scenario, where the (negative) effect becomes stronger over time. Similar to the effect on the output level, the negative effect has its maximum for moderate policy intensities in the long run. Panel (b) illustrates that the declining productivity is linked with a negative policy effect on the vintage choice. On average, firms invest in less productive capital vintages even if, as we have assumed an identical evolution of the frontier for all simulations, the same menu of capital vintages is available at a time regardless of the policy intensity.

Before continuing the discussion in more detail and providing an explanation for the long-term effects, we can summarize the observations obtained so far in the following result:

Result 4: *Despite a positive effect on the investment activities in the short and medium term, the investment subsidizing policy does not generate additional output growth. Instead, it has no growth effect in the short and medium term but a negative*

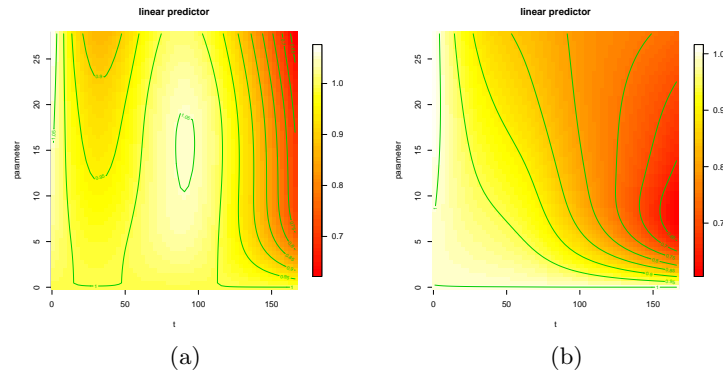


Figure 3.34: Policy effect on the percent standard deviation of firms' output (a) and capital productivity (b).

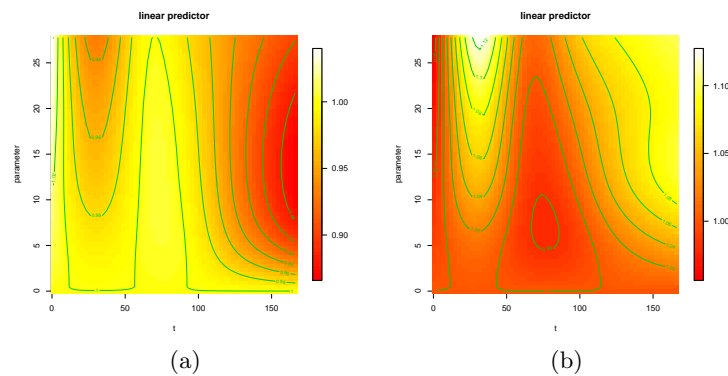


Figure 3.35: Policy effect on the output level of high-tech (a) and low-tech firms (b).

growth effect in the long run. At the same time, the policy has an employment-promoting effect. But the higher employment does not lead to more output since the policy causes also a negative effect on the technological productivity of the capital stock in the economy. In addition, the policy is associated with more inflation and leads to a higher public debt.

Even if there is almost no effect on the aggregated output in the short and medium term, the policy effects on investments, labor demand and the technology suggest the emergence of considerable dynamics within the firm population. This conjecture is supported by Figure 3.34, which illustrates the policy effect on firms' heterogeneity with respect to output (panel a) and technological productivity (panel b). Apparently, the heterogeneity of firms' output is differently affected by the policy over time. In the short term, the policy leads to a decreasing heterogeneity, while in the medium term the heterogeneity increases and in the long run declines again. Firms' heterogeneity with respect to the capital productivity declines monotonically throughout the simulation. Thus, the technological differences of firms become smaller over time, where the maximum effect can be observed for medium policy intensities at the end of the simulation.

Similar to the case of consumption subsidies, the policy effect on firms' output heterogeneity is caused by initially differing policy responses of low- and high-tech firms. But in this policy scenario, the firms respond in exactly opposite ways, namely high-tech firms by contracting (Figure 3.35 a) and low-tech firms by expanding (Figure 3.35 b). Apparently, as a major difference to the consumption subsidizing, low-tech firms rather than high-tech firms benefit mostly from the investment subsidies

in the first place. In the aggregate, the increase of output of low-tech firms offsets the declining output of high-tech firms such that no significant effect on total output can be observed (see above).

Why does the policy give low-tech firms more incentives to expand in the short term? The state of the economy at the beginning of the baseline scenario plays an important role to answer this question. In this phase, the output of high- and low-tech firms is diverging, i.e. high-tech firms expand while the low-tech firms reduce their output (compare Section 3.4.2). Moreover, high- and low-tech firms differ with respect to wage offers at the outset of the simulation. While high-tech firms offer competitive wages for high-skilled workers, low-tech firms post competitive wage offers for low-skilled workers. At the same time, the employment level of high-skilled workers is considerably higher. As a consequence, a great share of the stock of available workers consists of low-skilled workers. This implies a structural disadvantage of high-tech firms in hiring additional workers during this period.

The policy does not immediately generate more demand in the short term. As illustrated above, the effect on the total market emerges rather at a slow pace. Hence, short-term expansion of high-tech firms could be reached only with an aggressive pricing strategy that forces low-tech firms out of the market. But as they also face labor market rigidities which make aggressive pricing more expensive, high-tech firms assess this strategy as being non-profitable. In this case, the subsidies are taken as windfall gains without triggering further investments. At the same time, the initial investment level of low-tech firms is low, i.e. most of the low-tech firms appraise capital investments as not being worthwhile given the current market environment. With subsidized capital prices, investments become cheaper and the likelihood of an investment project to break even increases. This results in more investments of low-tech firms and consequently affects their production capacity. Together with the higher attractiveness for better available low-skill workers, an increased production capacity gives low-tech firms the opportunity to gain additional market shares.

The expansionary strategy of low-tech firms is associated with intensified labor market activities, where low-tech firms increase the base wage offers relative to that of high-tech firms (Figure 3.36 a). Thus, the initial gap in terms of base wage offers between low- and high-tech firms increases further in the short run. That way, low-tech firms become also more attractive for low-skilled employees (panel b) and lose some of their relative unattractiveness for high-skill workers (panel c). Thus, low-tech firms can attract more of the available workers and can increase their workforce relative to high-tech firms (compare Figure 3.36 d).

The base wage offers that firms need to rise to attract more workers result in higher wages and, eventually, they lead to higher unit labor costs. Since the wage offers grow faster for low-tech firms in the short run, they also cause a faster growth of labor costs for these firms (see Figure 3.37 a) At the same time, low-tech firms have to set prices more aggressively in order to ensure that the additionally produced output can actually be sold. High-tech firms in turn react on this competitive strategy with a passive pricing strategy. As a result, the ratio between prices of high- and low-tech firms increases (see panel b).

The increased relative costs and the lowered relative price of low-tech firms lead to a negative effect on the ratio of mark ups (see Figure 3.37 c). This relative decline of profitability limits the scope of action for keeping the aggressive competitive strategy and gives high-tech firms the opportunity to adjust the strategy toward a more competitive one. Eventually, the changing competitiveness is a reason why there is a reversal in output effects of the policy in the transition from the short to

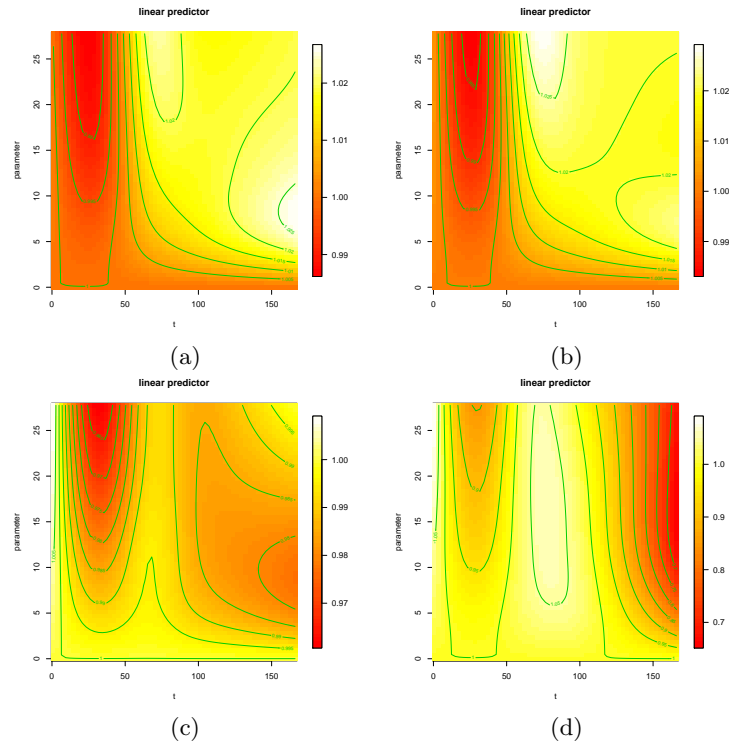


Figure 3.36: Policy induced change of the ratio of base wage offers (a), wage offers for low-skilled workers (b) and high-skilled workers (c) and number of workers (d) between high- and low-tech firms.

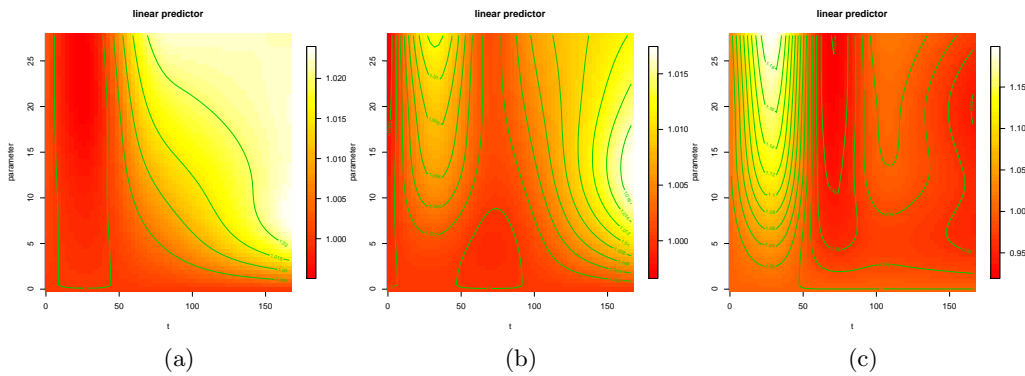


Figure 3.37: Policy induced change of the ratio of unit labor costs (a), prices (b), and mark-ups (c) between high- and low-tech firms.

the medium term.

The positive effect on the output of high-tech firms and the simultaneously occurring negative effect for low-tech firms are accompanied by a corresponding change of firms' labor market activities in the medium. High-tech firms have an increased labor demand and therefore increase the base wage offers more than low-tech firms. This effect is transferred to the skill specific wage offers. As a consequence, high-tech firms can expand their workforce and can eventually increase the output relative to low-tech firms. The number of workers being made redundant by low-tech firms is thereby smaller than the number of employees additionally hired by high-tech firms. Thus, the overall employment level rises in this phase.

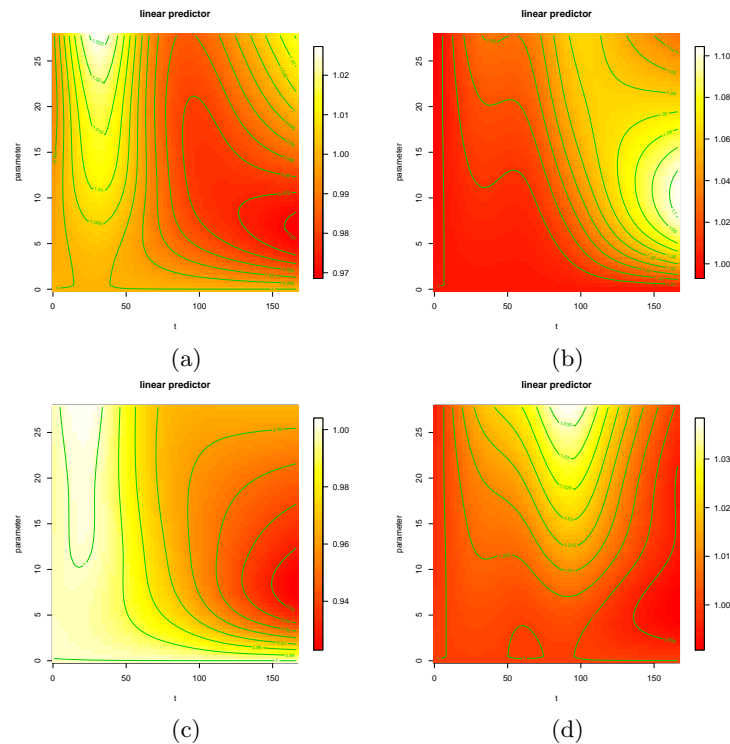


Figure 3.38: Upper row: policy effect on the general skill level of high (a) and low-tech firms (b); lower row: policy effect on the average specific skill level of high (c) and low-tech firms (d).

Due to an improved attractiveness for low-skilled workers, a greater share of the cohort of new employees hired by high-tech firms in the medium run belongs to the group of low-skilled workers. Hence, the average general skill level of high-tech firms is negatively affected (compare Figure 3.38 a). An enhanced recruitment of low-skilled workers has thereby two effects on high-tech firms. First, not only the general skill level but also the average specific skill level of high-tech firms declines (see Figure 3.38 c). This negative effect emerges as the additionally hired low-skill workers have a lower specific skill level compared to the incumbent workers. This is due to the fact that these workers have mostly been employed by low-tech firms. And second, the increased employment of low-skill workers and the consequential reduction of the general skill level have an effect on the vintage choice. Since decreased general skills lower the firm's perspective of taking advantage of high-productive vintages, high-tech firms have less incentives to invest in more productive technologies (see Figure 3.39 a). This in turn has an impact on the productivity of the capital stock in the medium term (see panel c), which is gradually declining compared to the base scenario. Moreover, as the technological productivity interacts with the specific skills of employees, it also contributes to a further reduction of the average specific skill level of high-tech firms (Figure 3.38 c). Altogether, there is a negative effect on high-tech firms' productivity that dampens the positive evolution of their output.

At the same time, there is a positive effect on the vintage choice of low-tech firms, which has already started to develop in the short run (Figure 3.39 b). This positive effect can be explained by the short-term investment effect triggered by the policy that results in a stronger replacement of old capital by new machines.

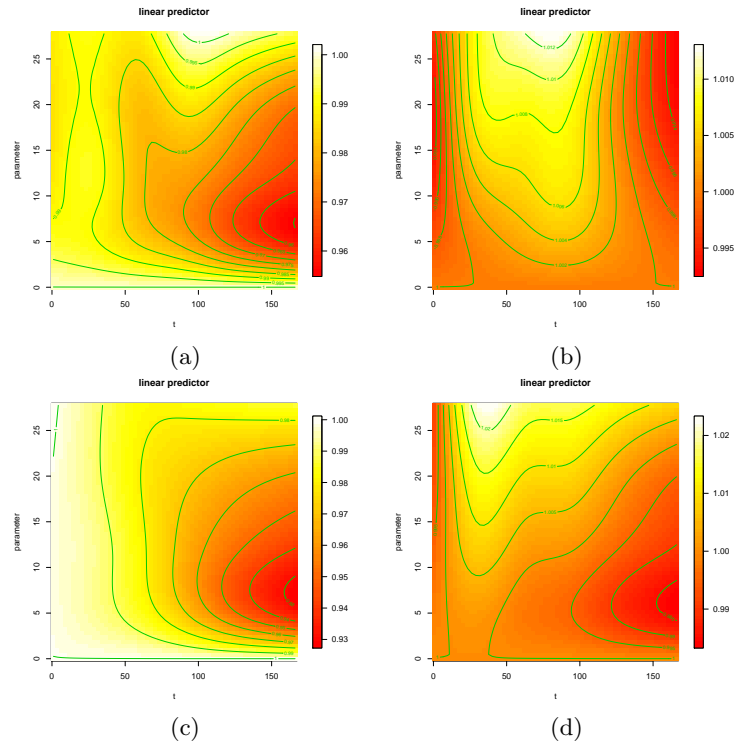


Figure 3.39: Upper row: policy effect on the vintage choice of high (a) and low-tech firms (b); lower row: policy effect on the capital productivity of high (c) and low-tech firms (d).

Thus, the share of more recent capital increases within the capital stock of low tech firms. This causes an increased productivity level (panel d), which reinforces the attractiveness to invest in more productive vintages. As a consequence, the productivity gap declines between high- and low-tech firms in the medium term. Moreover, low-tech firms are able to post wage offers for high-skilled workers that become more competitive. Therefore, low-tech firms can hire a growing share of high-skill workers, which also exhibit not only a high general skill level but also higher specific skills. Hence, there is a positive effect on the general skill level (see Figure 3.38 b) and the specific skill level (see Figure 3.38 d). This external effect on low-tech firms' productivity feeds back on the wage offers and amplifies firms' convergence in terms of general skills.

The relative output growth of high-tech firms in the medium run is associated with a more aggressive setting of wage offers, where the expansionary strategy launches a similar mechanism as described for low-tech firms in the short run. On the one hand, there is a negative effect on the relative unit labor costs of high-tech firms, which is mainly caused by the increase of the base wage offers (see Figure 3.37 a); on the other hand, high-tech firms pursue a more aggressive pricing strategy in order to expand the price gap to the competitors (compare Figure 3.37 b). Both effects result in a decline of relative mark-ups between high- and low-tech firms (Figure 3.37 c). Thus, as time elapses, high-tech firms are forced to relax their competitive strategy. In combination with the stronger convergence of firms' productivity, this leads to a ceasing of the positive output effect for high-tech firms and a strengthening of low-tech firms in the transition from the medium to the long term (see Figure 3.35).

The subsiding output effect coincides with increasing labor shortages of high-tech

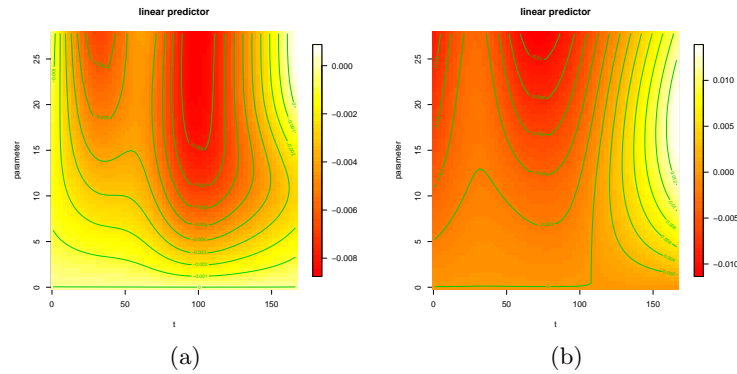


Figure 3.40: Policy effect on the production rate of high (a) and low-tech firms (b).

firms. Panel (a) of Figure 3.40 shows that the growing difficulty of filling vacancies leads to an increasing gap between planned and actual output. Unlike high-tech firms, low-tech firms undergo an increase of the output gap earlier in the medium term, namely when high-tech firms still have a high competitiveness (panel b).

In the long term, the policy has a fostering effect on the output convergence between high- and low-tech firms. The output of high-tech firms drops by up to 12% while the output of low-tech firms increases by up to 10%. The output gain for low-tech firms cannot compensate the output loss of high-tech firms such that the overall output effect is negative. But what causes the strong negative effect on the output of high-tech firms in the long run?

The negative effect on the output of high-tech firms and the simultaneously occurring positive effect on the output of low-tech firms are mainly driven by a complex interplay of cost and productivity dynamics in the long run. Figure 3.39 (c) and (d) demonstrate that the productivity level of high- and low-tech firms declines relative to the baseline scenario. But the productivity reduction of high-tech firms is stronger so that the productivity tends to converge in the long run.

A main driver of the change of firms' productivity is the policy effect on the vintage choice. For high-tech firms, one can see that the strength of the negative policy effect differs depending on the size of the policy intensity; for stronger policy intensities the effect is almost negligible, whereas it becomes more pronounced with a reduced intensity and reaches a maximum strength at an intensity level of about $\mu = 7.0$ (Figure 3.39 a). The strong impact at around $\mu = 7.0$ in the long term coincides with the strong negative effect on the general skill level. This suggests that the change of the general skill distribution plays a major role for the long term effect on the vintage choice.

But the general skill dynamics cannot completely explain the properties of the emerging effect. Rather, the vintage choice of high-tech firms is additionally affected by two other emergent phenomena, which interfere with the change of the skill distribution. The first is the policy impact on high-tech firms' output gap (see above). In the transition from the medium to the long term, high-tech firms experience an increase of the output gap caused by labor shortages. In general, this can increase the incentives to invest in vintages with a higher productivity because, given a sufficient general skill level, firms can substitute lacking labor by a better technology. In Figure 3.40 (a) one can see that the change of the output gap is the strongest under high policy intensities such that in this case firms might have more incentives to invest in more productive technologies. The second effect that counteracts the negative effect of lower general skills on the vintage choice can be seen in panel (a) of

Figure 3.41. In this panel, we show how the policy affects the average contribution of high-tech firms' investments to the capital stock of these firms. Apparently, high-tech firms' investments seem to be less fragmented when experiencing the negligible effect on their vintage choice in the long term (i.e., for high policy intensities). A low level of fragmentation means that investments show a higher lumpiness and, on average, the new acquired capital accounts for a larger share of the total capital of the investing firm. In this case, the vintage choice is more important because new capital has a stronger impact on the average productivity. Then, the lumpier investment behavior of high-tech firms has a choice effect toward higher vintages. If, in contrast, the investment accounts only for a small share of the capital stock, then the vintage choice becomes less important. This can be observed for lower levels of μ , where it leads to an amplification of the negative effect of the general skill dynamics on the vintage choice.

It is also the interaction of investment fragmentation with general skill dynamics that contributes to the policy effect on the vintage choice of low-tech firms in the long run (compare Figure 3.39 b). The positive effect on the general skill level of low-tech firms overcompensates the increasing investment fragmentation that arises for medium levels of μ (see Figure 3.41 b). For high policy intensities, the effect on the average general skill level becomes weaker such that the effect of the investment fragmentation dominates. In this case, the average vintage choice declines. This reduction is additionally amplified by the declining positive effect on the specific skills that has emerged for high policy intensities in the medium run (see Figure 3.38 d). The decreased specific skills in combination with a low level of general skills reduce the prospects of investing in more-productive vintages.

Besides the converging productivity, a further channel that affects the long-term convergence of output arises through the cost dynamics. In the short and medium term, we have observed that expanding firms incur a stronger increase of unit labor costs. This dampens and counteracts the expansionary strategy of these firms. But in the long term, when low-tech firms are expanding and high-tech firms are exposed to a strong negative output effect, there is no such counteracting effect on the relative unit costs (compare Figure 3.37 a). Instead, the ratio between unit labor costs of high- and low-tech firms increases further.

In the discussion of the base scenario in Section 3.4.2, it has been pointed out that the gap between low- and high-tech firms in terms of unit labor costs converges gradually over time. With the persistent positive effect on the relative unit labor costs under the policy in the medium and long run, the convergence of firms' competitiveness is even accelerated. For the long term, this means that in absolute terms, high-tech firms have already lost their competitiveness. Thus, there are no cost advantages of high-tech firms any more. At the same time, high-tech firms pass the rising costs on their prices such that there is also a faster convergence and, eventually, a complete catch-up of prices (see Figure 3.37 b). Altogether, the complete loss of their competitive advantage contributes to the strong effect on firms' output convergence in the long run. In this period, high-tech firms shrink faster than the market such that low-tech firms can take over market shares from their high-tech competitors.

But what drives these long-term cost dynamics? As pointed out earlier in the discussion, the base wage offer is a major determinant for unit labor costs. In Figure 3.36 one can see that the ratio between base wage offers of high- and low-tech firms evolve differently in the long run depending on the intensity level of the policy. For moderate levels of μ , there is a positive effect on the ratio, which means

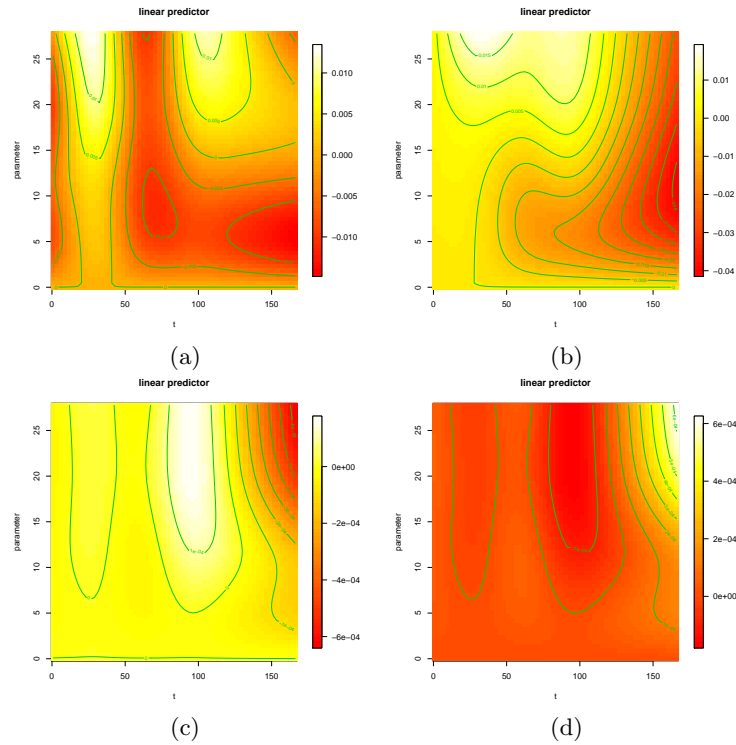


Figure 3.41: Upper row: policy effect on the average ratio between purchased capital and existing capital of investing high (a) and low-tech firms (b); lower row: policy induced change of the deviation of the individual from the economy-wide productivity growth for high (c) and low-tech firms (d).

that base wage offers of high-tech firms grow faster than those of low-tech firms. This positive effect is a response on a self-enforcing mechanism that emerges for moderate intensities: the convergence of firms' productivity reduces the relative wage offer for high-skill workers. Then, the reduced attractiveness has a negative effect on the average general skill level of high-tech firms, which in turn affects the vintage choice negatively. Since the vintage choice determines the speed of productivity convergence, also the productivity convergence is reinforced. But if the relative wage offer for high-skill workers declines without gaining additional attractiveness for low-skill workers, then it becomes even more difficult for high-tech firms to hire workers. As a consequence, these firms are forced to increase the base wage offers, which induces a relative increase of unit labor costs.

For high policy intensities, there is no significant change of the impact on the ratio of base wage offers. Hence, the number of posted and left over vacancies seem to be balanced between high- and low-tech firms. In this case, the policy effect on base wage offers of high- and low-tech firms offset each other. Furthermore, there is almost no convergence of firms' productivity such that high-tech firms can keep some of their relative attractiveness for high-skill workers. Nevertheless, one can observe a positive effect on the relative unit labor costs for high policy intensities in Figure 3.37. This positive effect is driven by a change of the growth of firms' productivity. As explained in Section 3.2.6, the wage of incumbent workers increases with the average growth rate pr_{t-1} of the aggregated capital stock in the economy. Thus, depending on whether the productivity growth of a single firm is below or above the economy-wide growth rate pr_{t-1} , the wages grow faster or slower than the firm's individual productivity. This leads either to increasing or to decreasing unit

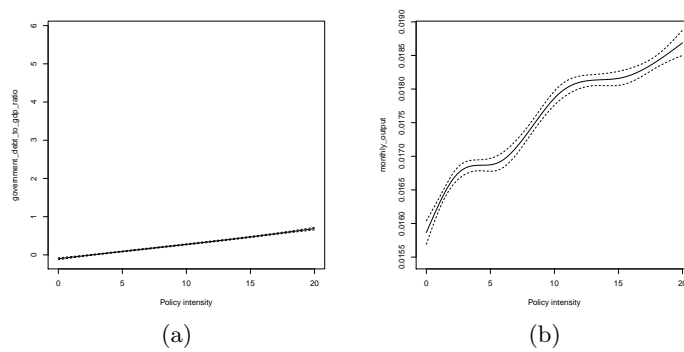


Figure 3.42: Spline-smoothed policy effects of the technology subsidizing on the government debt GDP ratio (a) and the average annual growth rate (b).

costs. In the lower row of Figure 3.41, we depict the change of the average deviation of firms from the economy-wide productivity growth compared to the base scenario (panel c for high-tech firms, panel d for low-tech firms; note that self-evidently panel c and panel d are perfectly mirrored). While there are apparently only small changes for most of the simulation time with no significant effects on the relative costs, high-tech firms experience a strong negative change of the deviation of the productivity growth for high policy intensities. This growing deviation causes rising unit labor costs of high-tech firms. Therefore, a positive effect on the relative unit labor costs arises for high values of μ , even if the relative base wage offers as the most relevant cost driver are not substantially affected.

To put all this together, the observations regarding the effects of the investment subsidizing policy within the firm population can be summarized as follows:

Result 5: *The investment subsidizing policy has a differing effect on firms' heterogeneity with respect to output. While there is a slight reduction in the short run and a slight increase of the heterogeneity in the medium term, the policy causes a strong reduction of the heterogeneity in the long term. In contrast, the policy leads to a gradual decline of firms' heterogeneity with respect to the productivity throughout the simulation. These results are driven by a different response of low- and high-tech firms on the policy in the short run, where low-tech firms benefit from the policy and, consequently, expand their production in the first place. This triggers cost and wage dynamics, which in turn induce effects on the dynamics of firms' average general skills and productivity. Eventually, the emerging convergence of firms' productivity and unit costs result in a complete loss of competitive advantages of high-tech firms in the long run. As a consequence, low-tech firms are able to catch up to high-tech firms in terms of output levels.*

3.4.6 The Technology Subsidy Policy

The technology subsidizing policy is the third stabilization policy that has been identified as being successful in smoothing the business cycle in Section 3.4.3. The general principle of this policy is similar to the principles underlying the investment policy. There is, however, a crucial difference between the policies: in case of the technology policy only those investments are subsidized that will flow into the most up-to-date technology. Likewise the consumption and investment subsidizing policy, we have shown that the technology policy leads to a significant reduction of the

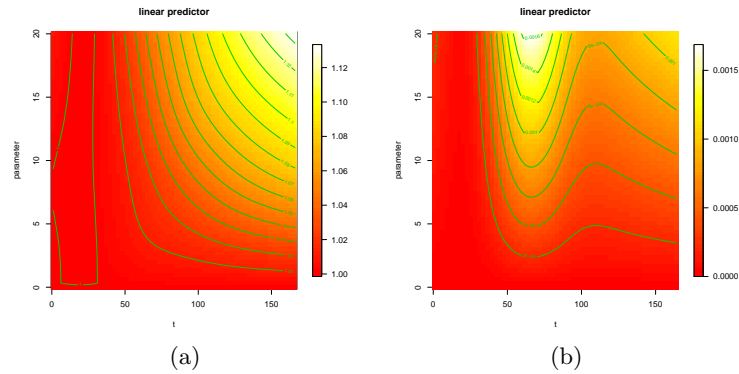


Figure 3.43: Spline-smoothed policy effects of the technology subsidizing on the evolution of aggregated output (a) and the evolution of quarterly growth rates (b).

business cycle volatility, but the achievable reduction is smaller than for the other two policies.

Despite this obvious disadvantage, the technology policy has two effects that seem to make the policy superior. First, the policy has the weakest effect on the government debt (see Figure 3.42 a). While without policy the government is almost unindebted after 500 months, the debt level grows with an increasing policy intensity. But compared to the consumption and investment policy, the increase is much smaller. At the highest intensity of $\mu = 20.0$, the debt ratio is below 100% of GDP. For the highest intensity of the investment policy, the debt is more than twice as high as and for the consumption subsidy policy it is even six times higher than GDP. Second, the policy has the strongest effect on the long-term growth of the economy. In panel (b) of Figure 3.42 one can see that the average annual growth rate increases steadily with the policy intensity from 1.6% to 1.9%. The maximum average growth rate of the consumption policy has been observed at a level of 1.68% p.a. and the growth effect of the investment subsidy has been even negative.

In Figure 3.43 we show how the policy affects the evolution of the aggregated output over time. Panel (a), which depicts the effect on the output level, illustrates that the additional average growth is translated into a growing output premium. Apparently, the impact becomes stronger with the policy intensity; for the highest value of μ , the real output is about 13% higher than in the baseline case after 500 months. Panel (b) indicates that the policy generates an unsteady growth effect without any growth-promotion in the short run but with a considerable growth boost in the medium and long term.

The idea behind the technology policy is to provide incentives for firms to invest in the best practice technology. The policy reduces only the price of the most productive vintage with the result that it becomes more rewarding to invest in the latest technology. This might increase the speed of technological diffusion and, through a consequently higher productivity in the economy, it might generate additional and sustainable real growth. Figure 3.44 (a) shows how the policy affects the average vintage choice of firms. It can be seen that the average productivity of the acquired capital is significantly higher than in the base scenario. Thus, the policy seems to affect the average vintage choice of firms. Moreover, the effect seems to become stronger over time but also stronger for higher policy intensities. Panel (b) shows the impact of the policy on the average productivity of the capital stock. One can see that through the promoted vintage choice, the distance to the base scenario increases gradually over time where again the impact of the policy depends on the

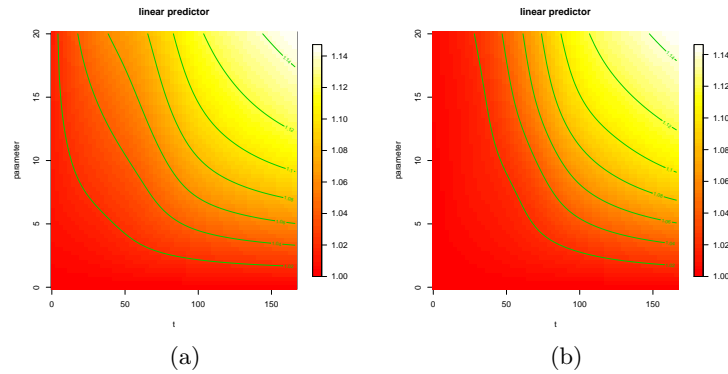


Figure 3.44: Spline-smoothed policy effects of the technology subsidizing policy on the evolution of the vintage choice (a) and the capital productivity (b).

intensity of the policy. Quantitatively, the strength of the effect on capital productivity resembles the effect on the output trajectory. Therefore, it appears that most of the growth of total output is driven by a faster diffusion of new technologies.

According to the wage adjustment rule described in Section 3.2.6, the productivity growth triggered by the policy is passed on the wages of workers and, therefore, causes additional growth of the nominal wages. In this case, however, the resulting higher labor costs are compensated by higher productivity such that firms' unit labor costs are not forced up. Furthermore, there is only an increased labor demand at the outset of the simulation for high policy intensities. In the medium and long run, the number of posted vacancies is even lower than in the base scenario (see Figure 3.45 a). In this phase, the strongest reduction of the number of offered jobs can be observed for medium policy intensities. As indicated in panel (b), the policy effect on the vacancies provokes a similar effect on the base wage offers. Driven by the higher labor demand in the short term, the base wage offers is higher than in the base scenario. But in the long term, the positive effect on the base wage offers declines and becomes negative. As argued in the discussion of the other policies, the base wage offer leads to wage increases that are not compensated by productivity gains and are therefore cost relevant. Consequently, the policy effect on the unit labor costs is positive in the short and becomes negative in the long term. Panel (c) of Figure 3.45 plots the corresponding deviation of the growth rates of unit labor costs from the base scenario. It indicates a slight positive deviation in the short and a strong negative deviation in the long term.

Two implications can be obtained from these observations. First, with the nominal wages also the nominal consumption budget increases over time. This can be seen in panel (d) of Figure 3.45, which depicts the effect on the nominal consumption budget. And second, the low cost effects of the policy avoid a similar inflation pressure as it has been observed for the consumption and investment policy.

Figure 3.46 displays the inflation effect, where panel (a) illustrates the average annual inflation rate dependent on the policy intensity and panel (b) shows the policy induced deviation of the quarterly inflation rate from the inflation rates of the base scenario. Apparently, the policy has almost no effect on the average annual inflation rate. Thus, it remains at a level of about 1.85% regardless of the policy intensity. Panel (b) indicates that if the time-averaged effect is disaggregated, it turns out that the policy also causes changes of the inflation; in the short and medium term, the effect is positive while in the long term the effect becomes negative. The negative long-term effect corresponds with the negative effect on the growth rate of unit

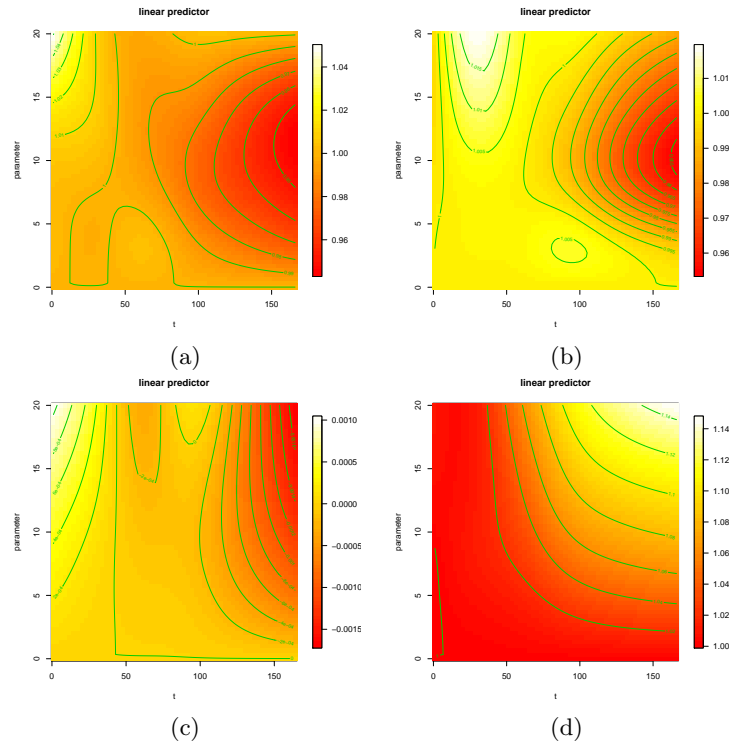


Figure 3.45: Spline-smoothed policy effects of the technology subsidizing policy on the evolution of posted vacancies (a), base wage offers (b), growth rates of unit labor costs (c), and total consumption budget (d).

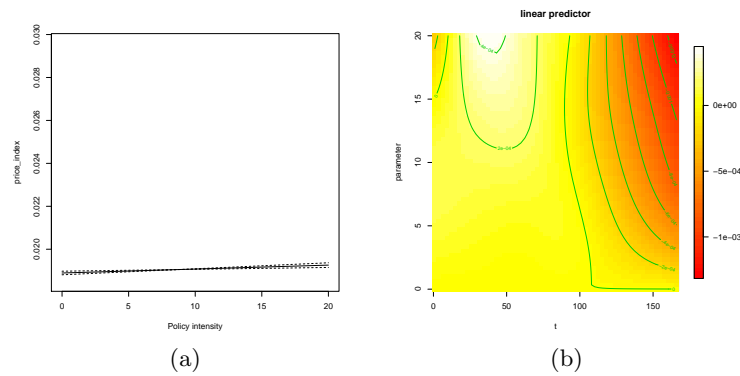


Figure 3.46: Policy effect on average annual inflation rate (left) and the evolution of the change of quarterly inflation rates (right).

labor costs. However, the strength of the effects that emerge at the different stages of the simulation is relatively weak, especially if compared to the additional growth of the nominal consumption budget. Hence, only a small share of the additionally generated nominal demand is inflated. As a consequence, the policy generates not only nominal demand but also a considerable amount of real demand. This real demand can be satisfied as the economy becomes more productive in the aggregate.

In Figure 3.47 (a) we show how the quantitative investment decision is affected by the policy. Apparently, the policy triggers a higher investment level in the short and for high policy intensities also in the medium and long run; whereas for the other instances the investment level is lower than in the base scenario. While the investment level and, therefore, the capital stock is higher in the short run, one

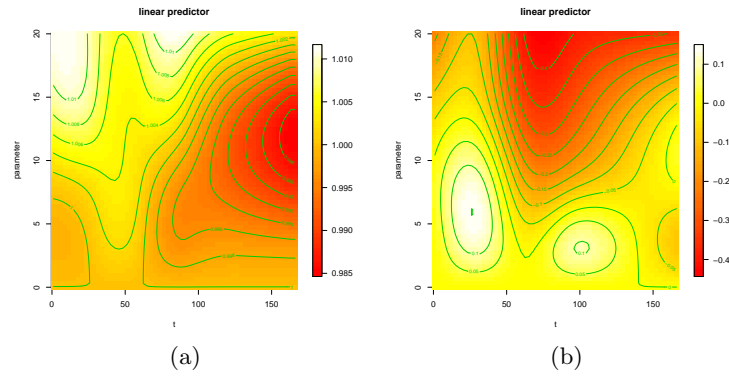


Figure 3.47: Spline-smoothed policy effects of the technology subsidizing policy on the evolution of investments (a) and the unemployment rate (b).

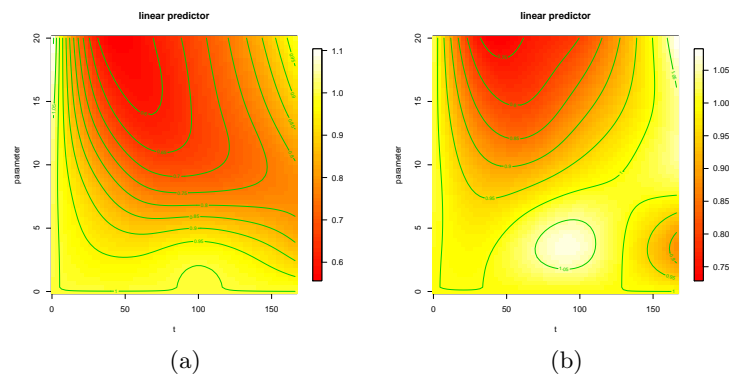


Figure 3.48: Policy effect on the percent standard deviation of firms' output (a) and capital productivity (b).

cannot observe a reduction of the unemployment rate in this period (see panel b). Instead, the policy effect on the unemployment rate is null and even slightly positive for low levels of μ . In the medium term, a positive employment effect emerges that reduces the unemployment rate by up to 0.4 percentage points. This positive employment effect becomes less intense in the long term. Compared to the two other policies, the overall strength of the unemployment-reducing effect is substantially smaller.

Wrapping up the observations obtained so far, we can write the following qualitative result:

Result 6: *The business cycle smoothing by subsidizing the adoption of the best practice technology leads to strong and sustainable long-term growth. This growth effect arises through a faster diffusion of new technologies and the resulting more productive capital stock in the economy. At the same time, the policy is associated with only a small increase of public debts and has only weak effects on the inflation, where these effects are inflation-fostering in the short and inflation-reducing in the long run. Despite temporary negative employment effects, the policy leads to more employment in the medium and long run, where eventually the positive effect ceases.*

As in the discussion of the two other policies, we now turn to the policy implications for the heterogeneity of firms. The policy effect on firms' heterogeneity with respect to firm size and productivity is depicted in Figure 3.48. Likewise the other policies, the technology subsidizing policy generates non-linear dynamics for both

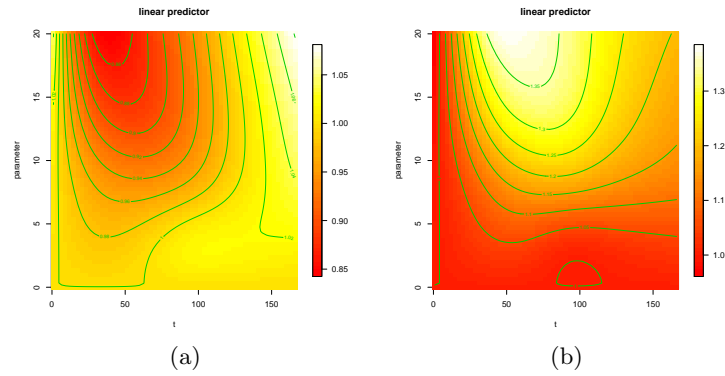


Figure 3.49: Policy effect on the aggregated output trajectory of high-tech (a) and low-tech firms (b).

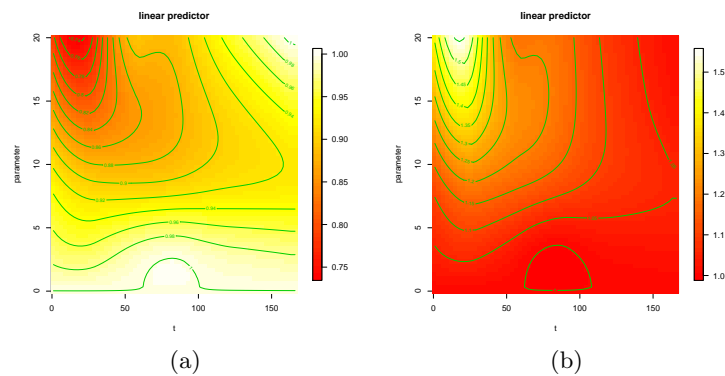


Figure 3.50: Policy effect on investments of high-tech (a) and low-tech firms (b).

types of heterogeneity. The policy leads to a strong reduction of the heterogeneity in the short term, but the heterogeneity-reducing effect starts to decline in the medium term and almost vanishes and becomes even positive in the long run. Thus, the policy tends to increase the heterogeneity of firms in the long term.

Similar to the two other policies, the effect on the evolution of the heterogeneity can be explained by emerging wage and productivity dynamics that are triggered by different short-term responses of high- and low-tech firms. In Figure 3.49 we depict the policy effect on the output trajectory of high-tech firms (panel a) and low-tech firms (panel b). In the short term, the technology policy generates a negative effect on the output trajectory of high-tech firms, whereas low-tech firms can increase their output. Both translate into a short-term reduction of output heterogeneity. In the medium term, however, high-tech firms intensify the output growth such that the gap to the output level of the base scenario declines. At the same time, the low-tech firms lower their output with the result that the output heterogeneity increases.

Figure 3.50 shows the corresponding effects on the quantitative investment decisions. In the short term, the investments of high-tech firms are strongly reduced, whereas the investments of low-tech firms are massively intensified, which is in concordance with the output effect. Later, as time elapses, the strength of the effects ease but the investment level of high-tech firms remains below the level observed in the base scenario while the investment activity of low-tech firms is higher throughout the simulation. But how does the policy affect the qualitative investment decision of high- and low-tech firms, namely the choice in which vintage to invest? The subsidizing of only the best practice technology increases the likelihood that a firm

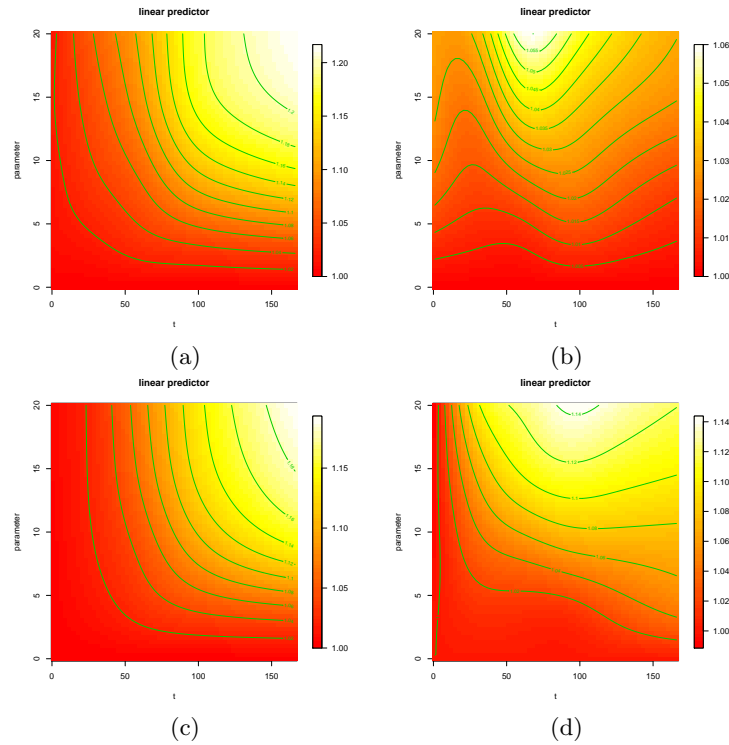


Figure 3.51: Upper row: policy effect on the vintage choice of high (a) and low-tech firms (b); lower row: policy effect on the capital productivity of high (c) and low-tech firms (d).

chooses this technology. The stronger the policy intensity is, the higher is the average subsidy rate and, therefore, the higher is the likelihood to invest in the best practice technology. Figure 3.51 depicts the effect on the average productivity of the vintage choice. It illustrates that the subsidization gives high- and low firms more incentives to invest in the most up-to-date technology. This can be seen as the productivity of the new capital is on average higher than in the base scenario throughout the simulation. However, the figure also shows that the effects evolve for high- and low-tech firms differently over time. While for high-tech firms the average vintage choice becomes gradually more productive throughout the simulation, the effect for low-tech firms is moderately positive in the short term, rises sharply in the medium term and declines again in the long term. Altogether, the subsidization does not prompt all firms to invest in the best practice. There is still a considerable gap between the productivity of purchased capital and the frontier productivity, which suggests that the vintage choice of low-tech firms is less affected than the vintage choice of high-tech firms by the policy.

In the lower row of Figure 3.51, we depict the effect on the capital productivity. Apparently, the effect on the productivity of high-tech firms resembles the effect on the vintage choice. Thus, driven by the subsidization of the best practice, the distance to the baseline case grows gradually over time. For low-tech firms, the evolution of productivity also resembles their vintage choice but the effect on the average productivity is higher than the effect on the vintage choice. This can be explained by the intensified investments of low-tech firms in the short run, which increase the share of newer and more productive vintages in the capital stock. This in turn raises the average productivity of the capital stock and widens the gap to

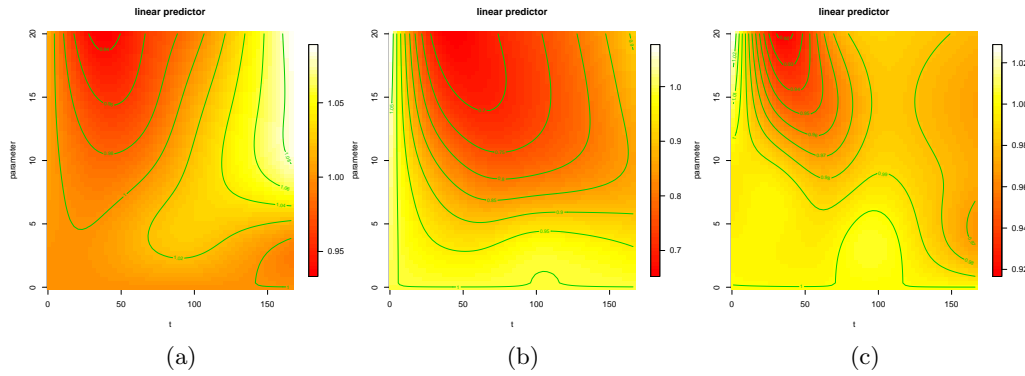


Figure 3.52: Policy effect on the ratio of capital productivity (a), the workforce size (b) and the vacancy filling rate (c) between high- and low-tech firms.

the base scenario.

The mechanism that leads to the initially differing competitive responses is basically the same as for the investment policy. Since the technology subsidizing does not affect the market demand in the short run, high-tech firms react in a passive way. This is because an increased production capacity would only lead to higher market shares when high-tech firms implement a predatory pricing strategy. At the same time, high-tech firms also face the structural disadvantage at the labor market that the more available low-skilled workers prefer to work for low-tech firms. As a consequence, high-tech firms would have to increase the base wage offers in order to attract more workers. This would increase the unit costs and would reduce the profit prospects for an aggressive competitive strategy. For low-tech firms, in contrast, the policy reduces investment barriers such that they have the opportunity to build up production capacities now. At the same time, they have better access to the available pool of workers and can hire the amount of employees required for an expansionary strategy.

But how does the targeting of the investment subsidies contribute to the differences to the case of untargeted subsidies in the investment policy scenario? An explanation is that the policy has quantitatively different effects on the productivity of high- and low-tech firms in the short term. At the outset of the simulation, the general skill distribution is highly polarized among high- and low-tech firms. Since high-tech firms have a high average general skill level, the vintage choice of these firms is already close to the frontier. In this case, the subsidizing has almost no impact on their productivity. On the contrary, due to the low average general skills, the vintage choice of low-tech firms is off the frontier. This productivity gap provides more scope for the policy to affect the productivity of low-tech firms. Actually, low-tech firms intensify their investments, where they choose the best practice technology more frequently. As a consequence, the productivity of the capital stock of low-tech firms shows a much higher growth rate than the productivity of high-tech firms. This results in a short-term technological catch-up (see panel a of Figure 3.52). The technological catch-up improves low-tech firms' position in the competition and amplifies the output convergence during the short run.

Panel (b) of Figure 3.52 indicates that low-tech firms increase the workforce compared to high-tech firms. This suggests that the initial output convergence is not only driven by a technological convergence but also by an emerging flow of workers from high to low-tech firms. The reduction of high-tech firms' workforce is

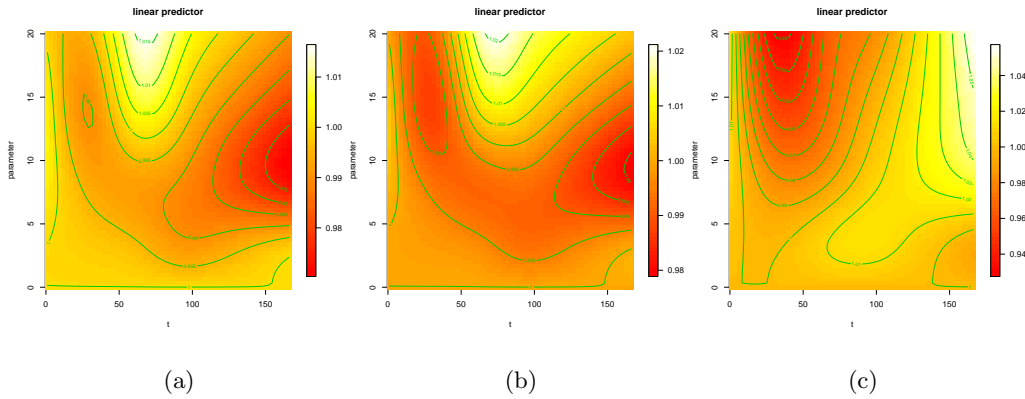


Figure 3.53: Policy effect on the base wage offers (a), wage offers for low-skilled workers (b), and wage offers for high-skilled workers (c) between high- and low-tech firms.

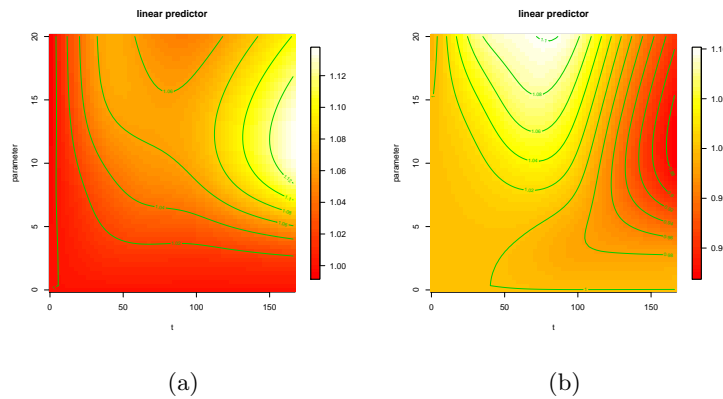


Figure 3.54: Policy effect on the general skill level of high-tech (a) and low-tech firms (b).

thereby not completely voluntary. Indeed, these firms cannot fill a growing share of their posted vacancies (see panel c, which depicts the relative policy effect on the ratio of posted vacancies that are successfully filled).

At the same time, low-tech firms increase the base wage offers in order to achieve the expansion of the workforce (see Figure 3.53 a). This short-term increase drives up the skill specific wage offers for low-skill and high-skill workers (panel b and c). As a consequence, low-tech firms become more attractive for both types of workers, where the effect on the relative wage offers for high-skill workers is amplified by the relative convergence of firms' productivity.

The differing evolution of firms' workforce in the short term has also implications for the general skill distribution. Due to the higher wage offers for low-skill workers, low-tech firms absorb most of these workers in this period. Thus, the number of low-skill workers employed by high-tech firms declines and a slight increase of the average general skill level arises during the short run (Figure 3.54 a). At the same time, the attractiveness of low-tech firms for high-skilled workers increases such that a growing share of their workers belongs to this skill group (see panel b). This positive effect reaches its maximum strength in the medium term and influences the vintage choice of these firms positively. This explains why a much stronger effect on the vintage choice of low-tech firms can be observed in the medium rather than in

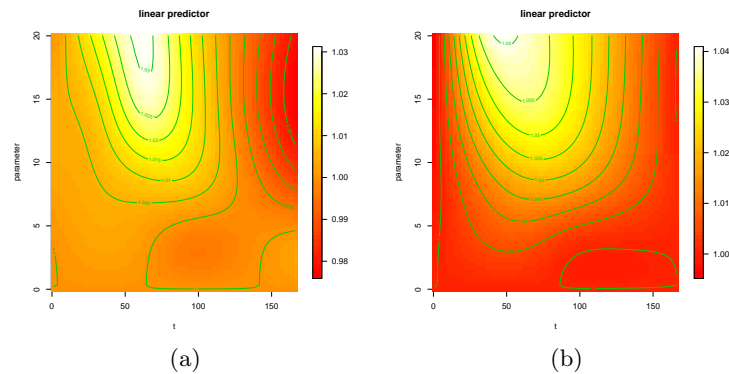


Figure 3.55: Policy effect on the ratio of unit labor costs (a) and prices (b) between high- and low-tech firms.

the short term.

As mentioned above, high-tech firms face an increasing difficulty to fill vacancies in the short run. At a certain point, the dominance of low-tech firms at the labor market becomes so prevailing that high-tech firms need to push the wage offers up in order to prevent a further labor tightening. As a result of this adjustment, there is a strong medium-term increase of the relative base wage offers towards high-tech firms (see Figure 3.53 a). The strong increase of the base wage offers is accompanied by the emergence of a positive effect on the wage offers for low-skill workers and a reduction of the, from the perspective of the high-tech firms, negative effect on the wage offers for high-skill workers (Figure 3.53 b and c). But the strong increase of the base wage offers also causes a strong increase of the unit labor costs in the medium term (Figure 3.55 a). Thus, the labor costs of high-tech firms grow more rapidly in this period, which limits the scope for a more aggressive competitive strategy.

But, eventually, the shift of relative competitiveness at the labor market towards high-tech firms triggers the cost-driving increase of low-tech firms' base wage offers. This gives high-tech firms the opportunity to gradually increase the output in the medium run (for which high-tech firms reduce the relative price, see Figure 3.55 b). The output expansion is accompanied by intensified investments where these investments increase the productivity of the capital stock of high-tech firms significantly through the targeting of the investment subsidies. The raised productivity widens thereby the spread between the wage offers for high-skill workers of the firms so that high-tech firms become much more attractive for this skill group. In the following, a self-reinforcing feedback effect emerges that causes the divergence of firms' capital productivity and output in the long term: Due to the improved relative attractiveness, high-tech firms can increase the share of high-skilled workers in their workforce, while the average general skill level of low-tech firms declines. As the subsidizing of the best practice technology is not as effective for low-tech firms as for their high-tech competitors, the declining general skill level reduces the average productivity of their vintage choice. As a consequence, the productivity level of low- and high-tech firms diverge further, which amplifies the advantage of high-tech firms at the labor market to hire high-skill workers. This in turn reinforces the polarization of the general skill distribution among firms. In the end, low-tech firms have no possibility for a technological catch-up as their general skill level is clearly inferior. Moreover, they cannot increase the workforce as soon as the low-skilled labor force is exhausted. For this reason, one can observe the long-term divergence of low- and high-tech firms in terms of output and productivity. Altogether, these findings can

be summarized in the following result:

Result 7: *The subsidizing of only the most recent generation of the technology leads to a reduction of firms' heterogeneity in the short run but to an increasing heterogeneity in the long run. The short-term convergence in terms of output and productivity is driven by lowered investment costs that lead to a relative output expansion of low-tech firms. This initial catch-up results in a relative loss of competitiveness of high-tech firms at the labor market and triggers adjustment processes of base wage offers through which high-tech firms can stabilize and, eventually, expand their relative output in the medium term. Since the subsidies provide more incentives for high-tech firms to invest in the most recent technology, the investments required for the output expansion increase the relative productivity of high-tech firms. This in turn raises their relative wage offers for high-skilled workers and causes eventually a strong selection mechanism with respect to general skills at the labor market. Finally, the emergent highly-polarized human capital allocation among firms ignites a feedback loop between wage offers, general skill dispersion and vintage choice that reinforces the process of productivity divergence. As a result, the heterogeneity of firms with respect to productivity and firm size increases in the long run.*

3.5 Robustness Checks

3.5.1 Sensitivity of the Model

The policy results discussed in the previous section have been obtained from simulations conditioned on the specific setting of exogenous model parameters. An overview of the parametrization can be found in Table 3.1 on page 93. In general, there is a high degree of arbitrariness in the choice of parameters, where differing parameter settings have potentially different impacts on the simulation outcome. In order to reduce the arbitrariness, the parametrization of the model has been based on a combination of a direct empirical estimation when empirical counterparts to parameters are available and an indirect calibration otherwise (compare Section 3.2.8). As a result, we have obtained a parameter setting that generates simulation output matching realistic features and reproducing empirically observed stylized facts. Nevertheless, the parametrization is still associated with considerable degrees of freedom and the employed estimation and calibration procedure can at best provide interval estimations for the parameters. But even if a reasonable range has been found for each parameter, a variation of single parameters within this range or interaction effects of a simultaneous variation of multiple parameters can have strong impacts on the simulation outcome. Those effects can considerably influence the results of the policy analysis. For this reason, it is important to analyze whether the policy analysis is robust against such a variation of model parameters.

A detailed analysis of the robustness of the policy experiments must include two steps. The first step is to test the general sensitivity of the model with respect to its parametrization. This means one has to check whether and how the behavior of the model changes when model parameters are varied within a reasonable range around their default values. The second step has to consider the impact of a variation of the parametrization on the results of the policy experiments. In this context, it has to be checked whether the qualitative findings of the policy analysis stay intact when model parameters are varied. This subsection will deal with the former step while the next subsection will consider the latter.

To test how the model behavior changes in response to a deviation from the calibrated parametrization, we define intervals of plus and minus 15% around the default values listed in Table 3.1. These intervals are the range in which each of the model parameters can be varied. As indicator variables that describe the model behavior subject to the parameter variation, we use the average growth rate of GDP and the business cycle volatility. We opt for these variables for two reasons: first, they have been key macro variables to describe the policy effects in the discussion of the experiments in Section 3.4. Second, the volatility describes the short-term behavior and the average growth the long-term behavior of the model so that we can distinguish short-term and long-term sensitivity. In order to analyze which of the listed parameters have significant effects, we have run 1000 Montecarlo simulations of the model, where in each run the parameter values have been randomly drawn from the defined parameter range. As a result, we have obtained 1000 pairs of observations for long-term growth and short-term volatility, each pair generated by simulations based on a random set of model parameters.

The relation between model parameters and the indicator variables growth and volatility can be formalized with means of statistical models. Each of the indicator variables is then defined as the dependent variable of a statistical model¹⁶, while the parameters of the simulation model are employed as covariates. Similar to the statistical analysis in the policy experiments, we formulate the relationship as a Generalized Additive Model (GAM) that relates the response variable (growth or volatility) to the predictor variables (parameters). The response variables linearly depend on unknown smooth functions of the predictor variables. Suppose Ξ is a vector containing all model parameters ξ_l with $l = 1, \dots, L$. and g is the dependent variable, i.e. long-term growth or short-term volatility. Then, the GAM can be written as

$$\hat{g} = g_0 + \sum_{l=1}^L s_l(\xi_l). \quad (3.51)$$

Table 3.3 shows the statistical summaries for the estimated meta-model of long-term growth on the left-hand side and volatility on the right-hand side. In order to control the possible impact of the growth rate on volatility, we have also included a smooth term for growth in the specification of the meta-model of business cycle volatility. The table provides the estimated degrees of freedom (edf) and the residual degrees of freedom (Ref.df) for each smooth term, as well as a test of whether the smooth functions significantly reduce model deviance. Moreover, it provides a fit for the parametric intercept (mean and standard error) and the table reports the adjusted R^2 , the pseudo R^2 (deviance explained) and the generalized cross validation score (GCV) as measures for the goodness of fit.

One can obtain some interesting insights from Table 3.3 regarding the behavior of the model. First of all, the constant or intercept is significantly positive for both dependent variables. This means, if the model is parametrized such that all parameter effects, i.e. all smooth terms $s(\cdot)$ are zero, then the model yields a positive average growth rate of 1.6% p.a. and a business cycle volatility of 1.7%. Thus, growth and short-term volatility are generic properties of the considered parameter subspace. Second, the table illustrates that a considerable number of smooth terms are statistically insignificant. If, however, a smooth term is insignificant, then the underlying predictor variable makes no significant contribution to explain the de-

¹⁶In order to distinguish the statistical model from the simulation model, we use in the following the term meta-model for the statistical model.

Parameter	growth					volatility				
	Smooth	edf	Ref.df	F	p-value	edf	Ref.df	F	p-value	
Growth	$s(g)$	1.00	1.00	0.03	0.87	2.89	3.42	2.59	0.04**	
Tax rate	$s(tax)$	3.01	3.51	13.76	0.00***	2.67	3.18	1.27	0.28	
Price sensitivity of consumers	$s(\gamma^C)$	1.00	1.00	1185.83	0.00***	1.70	2.09	1.00	0.37	
Depreciation rate	$s(\delta)$	1.00	1.00	1.68	0.20	1.00	1.00	1.03	0.31	
Discount rate	$s(\rho)$	1.11	1.21	850.76	0.00***	1.00	1.00	2.35	0.13	
Tech. progress	$s(\Delta q^{nv})$	1.00	1.00	16.30	0.00***	1.00	1.00	2.27	0.13	
Consumption adjustment	$s(\kappa)$	3.38	3.79	372.60	0.00***	3.47	3.84	190.41	0.00***	
Planning horizon investments	$s(T_{LT})$	1.00	1.00	0.73	0.39	1.00	1.00	1.03	0.31	
Expected volatility option pricing	$s(\sigma^V)$	1.00	1.00	2.02	0.16	1.89	2.31	3.36	0.03**	
Max. deferral period	$s(T_{Ex})$	1.00	1.00	2.95	0.09*	2.42	2.95	9.60	0.00***	
Debt repayment period	$s(T_{Loan})$	1.00	1.00	25.84	0.00***	3.36	3.78	2.34	0.06*	
ECB base rate	$s(r^C)$	1.00	1.00	0.08	0.78	1.00	1.00	0.64	0.42	
ECB mark-down	$s(mr^C)$	1.00	1.00	0.20	0.76	1.57	1.93	0.50	0.60	
Min. cash reserve	$s(\beta^b)$	1.29	1.53	1.73	0.16	3.24	3.69	2.99	0.02**	
Debt rescaling factor	$s(\omega)$	2.58	3.10	5.65	0.01**	1.73	2.14	1.26	0.29	
Threshold full dividends	$s(d)$	1.17	1.32	0.01	0.93	1.00	1.00	2.23	0.14	
Dividend payout ratio	$s(d^f)$	1.00	1.00	1.84	0.12	1.73	2.13	1.00	0.37	
Initial equity new firms	$s(s^F)$	3.51	3.86	3.00	0.08**	1.61	1.98	7.20	0.00***	
Wage update	$s(\varphi)$	1.00	1.00	0.43	0.65	1.00	1.00	0.46	0.50	
Wage reservation update	$s(\psi)$	1.61	1.99	6.22	0.01**	2.24	2.73	43.47	0.00***	
Expected variance demand	$s(\sigma^2)$	1.13	1.25	13.72	0.00***	1.00	1.00	25.75	0.00***	
Service level	$s(\chi^S)$	1.00	1.00	1.09	0.34	2.93	3.43	3.04	0.02**	
Firm birth hazard	$s(h_{FB})$	1.68	2.08	0.69	0.40	1.00	1.00	1.25	0.26	
Basel Capital req.	$s(\alpha^b)$	1.00	1.00	1.66	0.20	1.00	1.00	0.37	0.54	
Logit general skills	$s(\gamma^{gen})$	1.00	1.00	6.24	0.01**	1.00	1.00	6.67	0.01**	
Unemployment benefits	$s(u)$	1.00	1.00	0.00	0.96	1.42	1.71	0.22	0.77	
Upper bound firing	$s(q^{up})$	1.00	1.00	0.016***	0.017***	0.016***	0.017***	0.016***	0.017***	
Constant				(0.00002)	(0.00002)			(0.00001)	(0.00001)	
Observations		1000		1000		1000		1000		
Adjusted R ²		0.791		0.791		0.678		0.678		
Deviance explained		72.5%		72.5%		69.4%		69.4%		
GCV score		3.5211e-07		3.5211e-07		1.941e-05		1.941e-05		
Log Likelihood		6,010.440		6,010.440		4,006.108		4,006.108		

Note: * p<0.1; ** p<0.05; *** p<0.01

Table 3.3: Spline estimated regression models for growth and volatility.

pendent variable and, therefore, could be removed from the regression model. In this case, a variation of that parameter has no effect on the model behavior, at least within the given parameter range. As a consequence, the dependent variable can be considered as being robust against a variation of this parameter around its default value. This does not imply that a variation of those parameters has no impact at all. But we focus on the neighborhood around the default values, in which all parameters can vary within the identical (relative) interval of plus and minus 15%.

If one compares the parameters that are significant for growth and for volatility, one can see that it is not necessarily the same set of parameters which is significant for both dependent variables. Thus, if one of the variables is robust against the variation of that parameter, this does not automatically mean that the whole model is robust.

In Figure 3.56 we display the estimated smooth functions for all parameters of the growth model that are reported to be statistically significant. The estimate of a smooth function can thereby be interpreted as individual profile or partial effect of a parameter. The red vertical lines in the panels show the default values of the parameters used in the simulations of the policy experiments.

Apparently, even if all smooth terms displayed in Figure 3.56 are statistically significant, the strength of the effects and, therefore, their importance for determining the average growth rate differ considerably. Some parameters have only a minor impact so that the average growth rate seems to be quite robust regarding their parametrization. At the same time, the model shows a higher sensitivity with respect to changes of other parameters, where especially those parameters yield strong growth effects that are related to the production and investment decision of firms. Most notably are the effects of the depreciation rate δ (panel a), the time horizon in the investment planning T^{LT} (panel c) and the parameter for the speed of technological progress Δq^{inv} (panel d). The effect for the depreciation rate is positive so that a higher depreciation rate leads to higher growth. This seems plausible as the depreciation influences the speed by which firms have to renew their capital stocks. The length of the planning horizon in the investment decision, which determines how many future periods are considered when computing the net present value of investment projects, has also a positive effect on the growth rate. The longer the horizon, the more periods contribute to the cash flow and the higher is the likelihood to break even. As a consequence, one can observe higher investment activities for higher T^{LT} that eventually lead to higher levels of growth. In this context, one would expect a negative impact of the discount rate on growth rates. Indeed, the effect is negative but the considered parameter range is too small so that the effect is insignificant here.

The speed of technological change has a strong and positive effect on the average growth rate of the economy. If the speed of the development of the best practice technology is improved, then also the productivity of the capital stock grows faster through the process of embodied technological change, which eventually leads to higher real growth. The other parameters listed in Figure 3.56 are statistically significant but the strength of their effects are quantitatively much weaker as those of δ , T^{LT} , and Δq^{inv} .

For the volatility the picture is more ambiguous (see Figure 3.57). The smooth term of the growth rate is statistically significant so that the growth rate contributes to the explanation of the business cycle volatility. But the estimated smooth function of growth rate (panel a) is non-monotonic so that one cannot derive a clear trend of its effect. There is one parameter, the investment planning horizon T^{LT} (panel c),

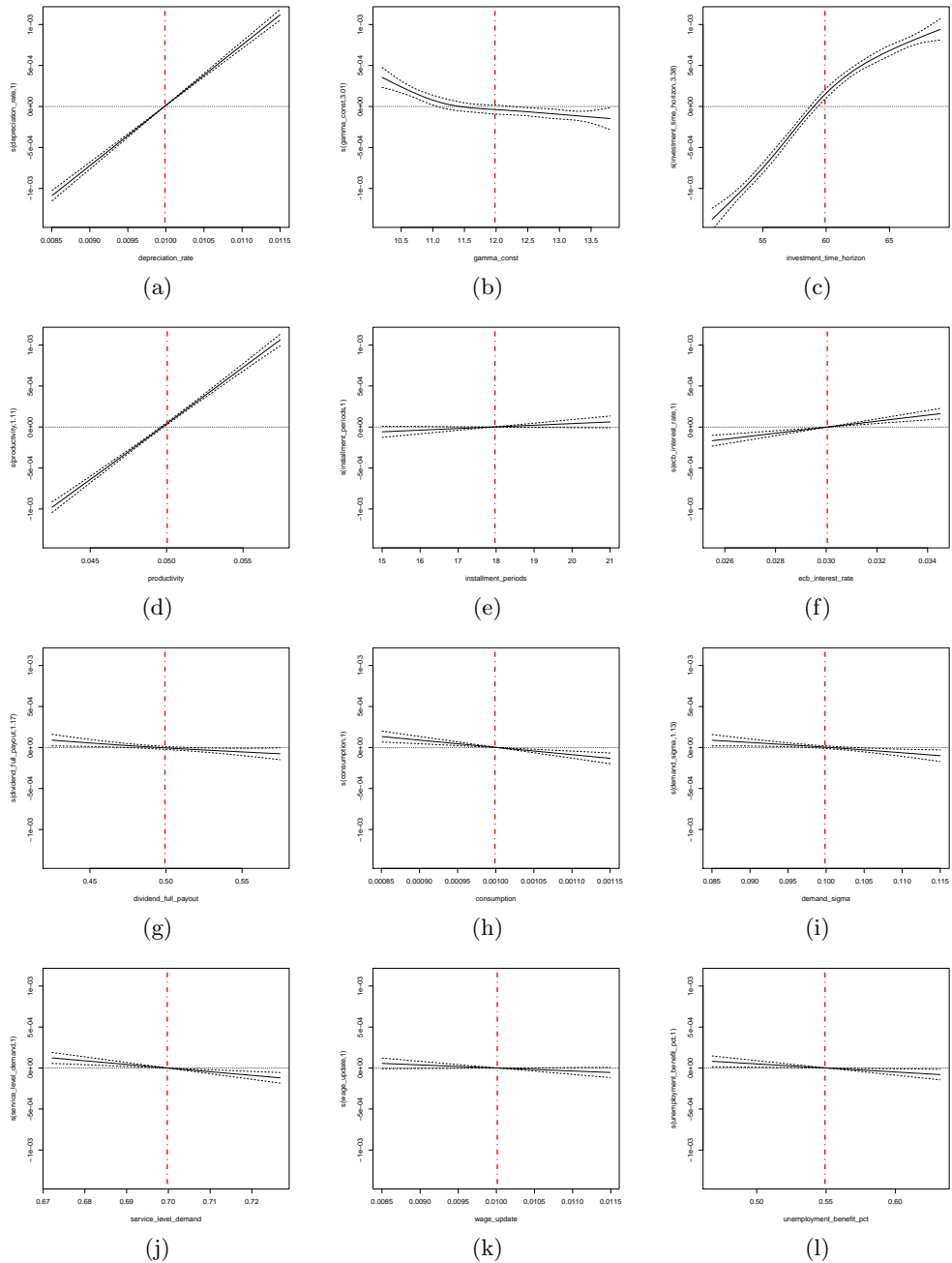


Figure 3.56: Estimated smooth functions of the statistical meta-model explaining long-term growth for the parameters of the simulation model depreciation rate δ (a), intensity of choice γ^C (b), investment planning horizon T^{LT} (c), technological progress Δq^{inv} (d), debt repayment period T^{Loan} (e), Central bank base rate r^C (f), threshold full dividend payout \bar{d} (g), consumption adjustment κ (h), expected demand variance σ_D^2 (i), service level demand χ^S (j), wage update φ (k), and unemployment benefit percentage u (l).

that has quantitatively a strong positive impact on the business cycle volatility. This suggests that the higher the investment level caused by taking more future periods into account, the stronger is the business cycle volatility. The service level (panel i) and the expected variance of demand σ_D^2 (panel j), both determining the buffer in

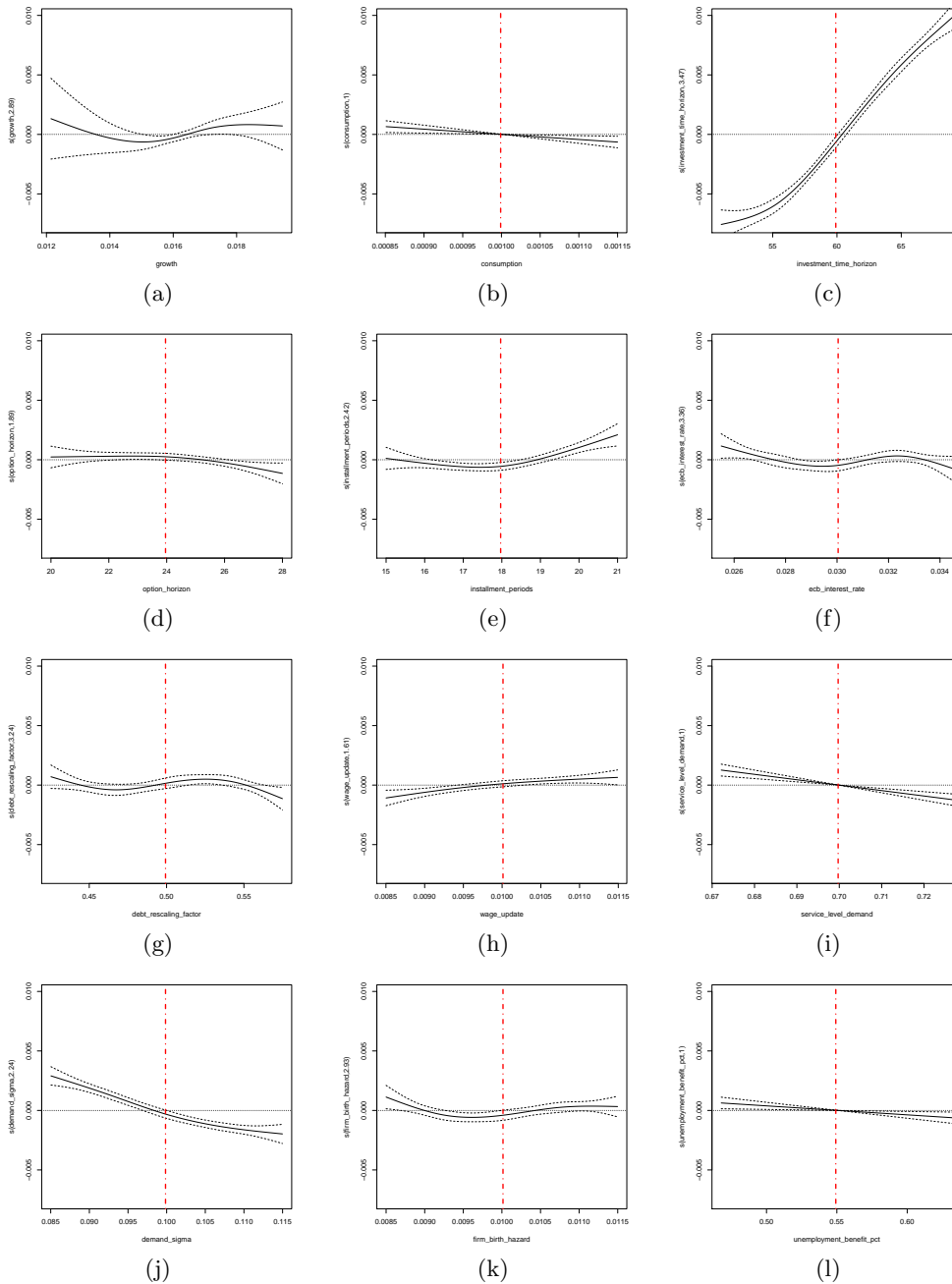


Figure 3.57: Estimated smooth functions of the statistical meta-model explaining short-term volatility for the parameters of the simulation model growth (a), consumption adjustment κ (b), investment planning horizon T^{LT} (c), maximum deferral period T^{Ex} (d), debt repayment period T^{Loan} (e), Central bank base rate r^C (f), debt rescaling factor ω (g), wage update φ (h), service level demand χ^S (i), expected demand variance σ_D^2 (j), firm birth hazard rate h^{FB} (k), and unemployment benefit percentage u (l).

the production planning, have a weaker but still a considerable positive effect so that a higher inventory buffer lowers the business cycle volatility. For the other parameters, the effects seem to be weak so that the volatility is robust against a variation of these parameters, even if the smooth terms are significant.

The goodness of fit of both models is relatively high but it can even be improved by incorporating interaction effects between parameters. Therefore, we extend the statistical models in Table 3.3 by introducing specific interaction terms for each pair of parameters. Formally, we can write the extended meta-model as

$$g = g_0 + \sum_{l=1}^L s_l(\xi_l) + \sum_{l=1}^L \sum_{k=1}^{l-1} I(\xi_l, \xi_k) \cdot te_{lk}(\xi_l, \xi_k). \quad (3.52)$$

In this case, $te_{lk}(\xi_l, \xi_k)$ are interaction terms using tensor product smoothing functions. $I(\xi_l, \xi_k)$ are binary variables that indicate whether the interaction effect for the pair ξ_l and ξ_k is significant¹⁷ in a reduced meta-model of only one interaction term, which is given by

$$g = g_0 + \sum_{l=1}^L s_l(\xi_l) + te_{lk}(\xi_l, \xi_k). \quad (3.53)$$

The estimations of the reduced meta-models yield 32 significant interaction terms for growth and 38 for volatility, where in the estimations of the full meta-models 6 and, respectively, 10 of them remain significant.

Incorporating the interaction effects in the regression models improves the explained deviance from 72.5% to 84% for growth and from 69.4% to 77.1% for volatility. Qualitatively, the interaction effects do not reshape the individual parameter profiles reported for the meta-models in Table 3.3. Furthermore, the single interaction effects have almost no quantitative impacts on volatility and growth rate.

Altogether, the sensitivity analysis has revealed a relatively high robustness of the model, where it seems to be quite robust against changes of most model parameters in the neighborhood around their default values. This observation can be made for both, the long-term growth and the short-term volatility of the business cycle. The estimated statistical models show a relatively high goodness of fit, where about 70% of the deviance can be explained by the variation of the parameters in isolation and additionally 10% of the deviance by incorporating interaction effects.

3.5.2 Robustness of Policy Findings

In the previous subsection we have analyzed the sensitivity of the model disregarding the three stabilization policies discussed in this study. General model parameters have been varied within an interval of 15% around their default values but parameters related to the stabilization policies have been set such that no policies was applied. As a consequence, the sensitivity analysis does not allow for any conclusion whether and how the results of the policy experiments in Section 3.4 change with a varying parametrization. In this subsection we provide robustness checks that study the effects of a variation of model parameters on the policy scenarios. We focus on the robustness of the qualitative results of the policy experiments for the three stabilization policies with respect to its primary objective, the reduction of the business cycle volatility and its effect on the long-term growth rate. As before, we restrict our analysis on the neighborhood around the default values that have been obtained from the (partially empirical) calibration.

The strategy to test the robustness of the policy findings is similar to the strategy used for the sensitivity analysis. For each stabilization policy we have run

¹⁷This means: $I = 1$ if the p-value < 0.1 , $I = 0$ otherwise.

simulations in which the parameter setting has been determined by independent and uniformly distributed random draws from the parameter range of 15% around the default values. But in contrast to the sensitivity analysis, we have varied the policy intensity parameter μ stepwise within the same range as used in the policy experiments in Section 3.4. For each of the corresponding values of μ , we have run 25 batch runs. The pooled simulations for each policy scenario can then be used to estimate generalized additive regression models for long-term growth and short-term volatility, in which model parameters and the policy intensity μ are deployed as covariates.

Regarding the variation of the parameters, there are two types of effects of particular interest; the one is the isolated effect of the policy intensity on growth and volatility, which can be used to generally check whether the random choice of model parameters changes the effect of the policy substantially. The second type are joint effects of μ with each of the model parameters that illustrate how the policy effects are affected by a variation of these parameters.

To extract the isolated effect, we formulate a GAM in which all model parameters and the policy intensity are wrapped in independent smooth functions. We obtain the following estimated model:

$$g = g_0 + s_\mu(\mu) + \sum_{l=1}^L s_l(\xi_l). \tag{3.54}$$

Again, ξ_l with $l = 1, \dots, L$ is the set of model parameters contained in vector Ξ . The estimated smooth function $s_\mu(\mu)$ indicates the isolated effect of the policy on the dependent variable g .

The joint effect of the policy intensity and a parameter ξ_k can be obtained by estimating the following GAM:

$$g = g_0 + \sum_{l=1}^{k-1} s_l(\xi_l) + \sum_{l=k+1}^L s_l(\xi_l) + te(\mu, \xi_k). \tag{3.55}$$

In this model, each parameter except ξ_k , for which the interaction is assessed, is included in independent smooth functions to capture their impacts on the dependent variable g . The tensor product smooth function $te(\mu, \xi_k)$ indicates the joint effect and can be interpreted as the effect of the policy intensity μ conditioned the parametrization of ξ_k . Note that in the following we discuss the interaction effects only for selected model parameters. For the business cycle volatility we present the interaction for the parameters investment planning horizon T^{LT} , expected demand volatility σ_D^2 , and service level in the production planning χ^S . For the average growth rate we limit the discussion on the depreciation rate δ , the investment planning horizon T^{LT} , the speed of technological change Δq^{inv} and the intensity of consumers' choice γ^C . We opt for these parameters as they have been reported in Section 3.5.1 to have the strongest impacts on the business cycle volatility and the average growth rate. We have also checked the interaction effects for the other parameters but, compared to the effects of the parameters above, they are qualitatively similar and quantitatively negligible.

Figure 3.58 depicts the isolated effects of the consumption subsidy policy estimated with GAMs as specified in Expression 3.54, where panel (a) displays the effect for volatility and panel (b) for growth rates. One can see that the effectiveness of the consumption subsidization does not qualitatively change to the results obtained in Section 3.4 (compare Figure 3.13 and 3.16); thus, the result that a subsidizing of

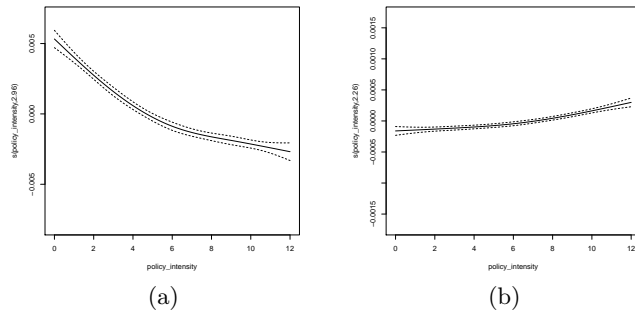


Figure 3.58: Smooth terms for the intensity of the consumption subsidy estimated for the GAM with volatility (a) and average growth rate (b) as dependent variables.

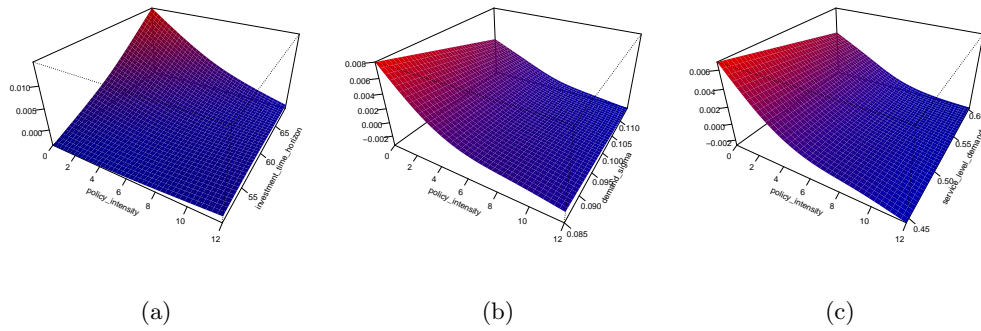


Figure 3.59: Joint smooth terms for the policy intensity of the consumption subsidy and the parameter investment planning horizon T^{LT} (a), expected demand volatility σ_D^2 (b), and service level of demand χ^S (c), estimated for the GAM explaining the business cycle volatility.

households' consumption leads to a reduction of the business cycle volatility and at the same time to a slight positive effect on the average growth rate in the economy shows a considerable degree of robustness against the parametrization of the model.

This observation does not change when looking at the joint effect of the policy intensity with each of the model parameters (estimated with GAMs described in Expression 3.55). In Figure 3.59 we show for the business cycle volatility the joint effects of μ with the parameters investment planning horizon T^{LT} , expected demand volatility σ_D^2 and service level in the production planning χ^S . Apparently, since all three plots indicate a monotonically decreasing area from west to east along the x-axis, the volatility reducing effect of the consumption subsidy is robust against a variation of these parameters. An exception can only be observed for low values of T^{LT} . When a short planning horizon is assumed in the investment decision, the policy has no effects on the business cycle volatility. However, this finding is not surprising as the sensitivity analysis has already pointed out that a reduction of T^{LT} is associated with a decreasing business cycle volatility.

We now turn to the growth effect of the consumption subsidizing policy. The joint effects of the policy intensity μ with the depreciation rate δ , the investment planning horizon T^{LT} , the speed of technological change Δq^{inv} , and the intensity of consumers' choice γ^C are displayed in Figure 3.60. All four panels indicate that an increase of the policy intensity μ is associated with an increasing average growth rate for any of the four parameters within the considered value range. Therefore, the

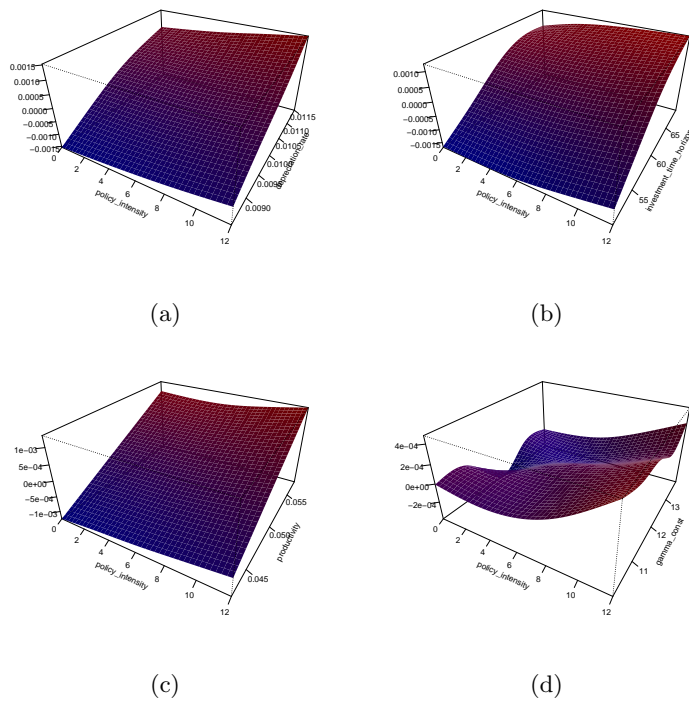


Figure 3.60: Joint smooth terms for the policy intensity of the consumption subsidy and the parameter depreciation rate δ (a), investment planning horizon T^{LT} (b), speed of the frontier growth Δq^{inv} (c), and the intensity of consumers' choice γ^C , estimated for the GAM explaining the average growth rate.

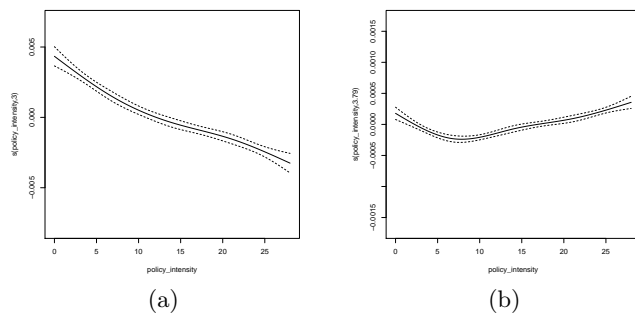


Figure 3.61: Smooth terms for the intensity of the investment subsidy estimated for the GAM with volatility (a) and average growth rate (b) as dependent variables.

slight positive growth effect of the policy, which has been observed in Section 3.4, stays intact if we vary the model parameters from their default value.

Also the analysis of the investment subsidizing policy reveals a high robustness of the key results of the policy experiment. Figure 3.61 depicts the isolated policy effects for volatility (panel a) and growth (panel b). As for the consumption policy, the isolated effects resemble the policy effects obtained in Section 3.4 under the default parameter setting (compare Figure 3.13 and 3.28). Hence, if we randomize the parameter setting in the neighborhood of the default values and we isolate the effect on volatility and growth, we still obtain a reduction of short-term fluctuation and a negative effect of the policy on the long-term growth. The effect on the growth rate seems to cease as policy intensity increases.

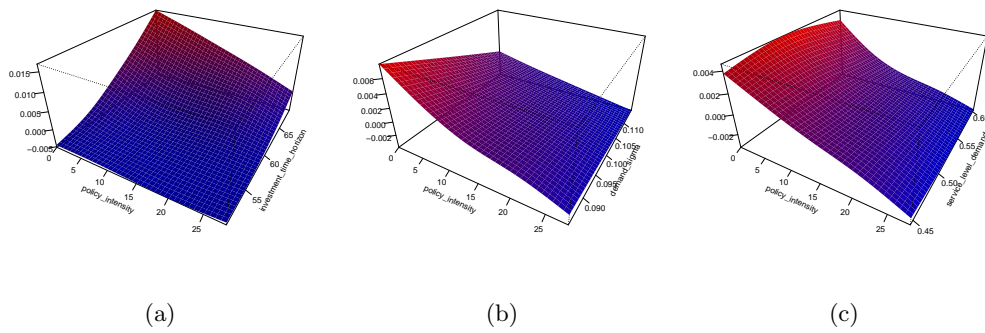


Figure 3.62: Joint smooth terms for the policy intensity of the investment subsidy and the parameter investment planning horizon T^{LT} (a), expected demand volatility σ_D^2 (b), and service level of demand χ^S (c), estimated for the GAM explaining the business cycle volatility.

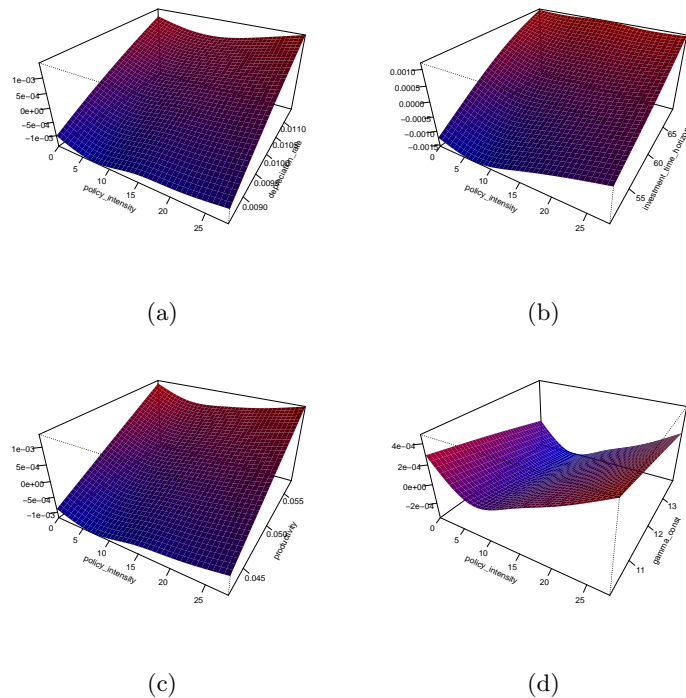


Figure 3.63: Joint smooth terms for the policy intensity of the investment subsidy and the parameter depreciation rate δ (a), investment planning horizon T^{LT} (b), speed of the frontier growth Δq^{inv} (c), and the intensity of consumers' choice γ^C , estimated for the GAM explaining the average growth rate.

Figure 3.62 and 3.63 show that these policy effects are qualitatively little affected when considering the interaction of the policy intensity with those parameters having strong effects on business cycle volatility and growth rates. One can see that the shape of the effects stays intact, where only for the planning horizon of the investment decision, T^{LT} , the effect on the business cycle volatility disappears for low values of T^{LT} (see Figure 3.62 a) and the effect on the growth rate disappears for high values of T^{LT} (see Figure 3.63 b).

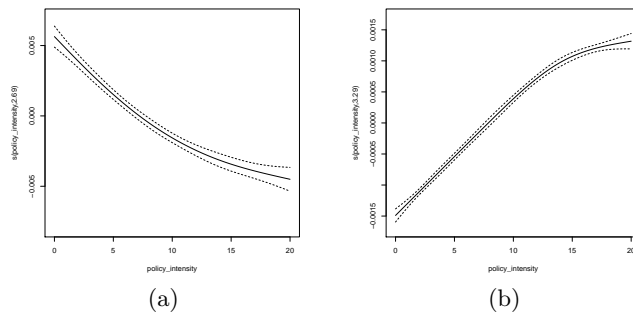


Figure 3.64: Smooth terms for the intensity of the technology subsidy estimated for the GAM with volatility (a) and average growth rate (b) as dependent variables.

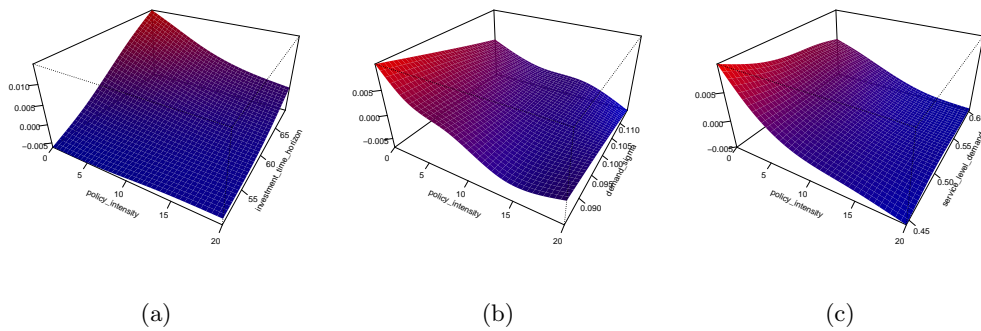


Figure 3.65: Joint smooth terms for the policy intensity of the technology subsidy and the parameter investment planning horizon T^{LT} (a), expected demand volatility σ_D^2 (b), and service level of demand χ^S (c), estimated for the GAM explaining the business cycle volatility.

Finally, Figure 3.64 to 3.66 illustrate the robustness of the policy findings for the technology subsidizing policy. Both, the isolated effects (Figure 3.64) as well as the joint effects (Figure 3.65 and 3.66) show a high similarity with the policy effects obtained from the policy experiments (compare Figure 3.13 and 3.43). This means the variation of the model parameters alters neither the business cycle volatility reducing effect of the policy nor its strong growth-fostering effect.

Altogether, a variation of model parameters in the neighborhood around their default values does not change the qualitative findings of the policy analysis. This means the results that we have obtained in Section 3.4 are apparently robust and valid not only for the specific parameter setting used for the policy experiments (see Table 3.1 on page 93). It should be noted that this does not mean that the effects identified in the policy analysis are generic results which can be obtained from any parametrization of the model. However, as pointed out above, the parametrization used for the experiments has not been chosen arbitrarily but has been obtained from a systematic attempt to estimate and calibrate the model. The underlying assumption for this parametrization method is that the parameter space is restricted by, on the one hand, empirically observed values for parameters that have empirical counterparts and, on the other hand, by values that lead to economically reasonable simulation outcomes for the other parameters. The parametrization in Table 3.1 represents such a specification. The robustness checks in this subsection have demonstrated that the policy experiments are robust in the neighborhood of

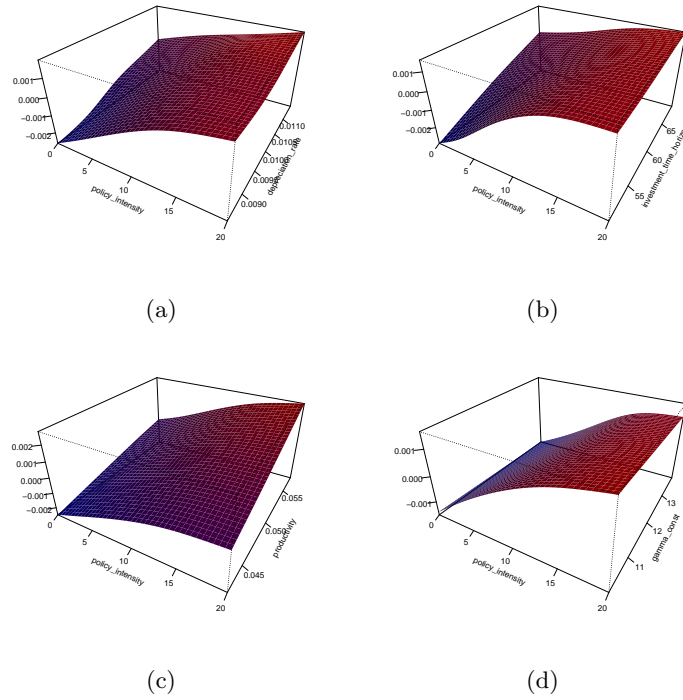


Figure 3.66: Joint smooth terms for the policy intensity of the technology subsidy and the parameter depreciation rate δ (a), investment planning horizon T^{LT} (b), speed of the frontier growth Δq^{inv} (c), and the intensity of consumers' choice γ^C , estimated for the GAM explaining the average growth rate.

this reliable parameter setting.

Besides the parametrization of the model, the initial condition of the economy has also an important impact on the simulation outcome. The initial condition describes the endowment and memory of agents with which they enter the first iteration of the simulation. In Section 3.2.8 we have explained that the start state used for the experiments has been a snapshot of a pre-simulation. The pre-simulation started with an equal initialization of all agents except for some variables as, for example, the general skill endowment of households. The iteration used as start state for the simulations has been chosen such that the simulation has passed the transient phase.

In the following, we want to demonstrate that the results from the policy analysis are also qualitatively robust against a variation of this specific start state. Therefore, we have run a set of simulations based on the default parametrization in which we varied the date T^{Pol} at which the stabilization policies are introduced for the first time. Actually, this leads to an expansion of the pre-simulation, so that also here the start states are not determined arbitrarily. The maximum deferral of the policy implementation is by 250 months so that we vary T^{Pol} between month 1 and month 250 (in the experiments, T^{Pol} has been set to 1). In order to make the indicators for the effectiveness of the policy comparable, we had to adjust the length of the simulations accordingly such that the total simulation time is $T^{Pol} + 500$ months. The business cycle volatility and the average growth rate are then computed for the last 500 months.

We estimate the impact of T^{Pol} on the business cycle volatility and the average

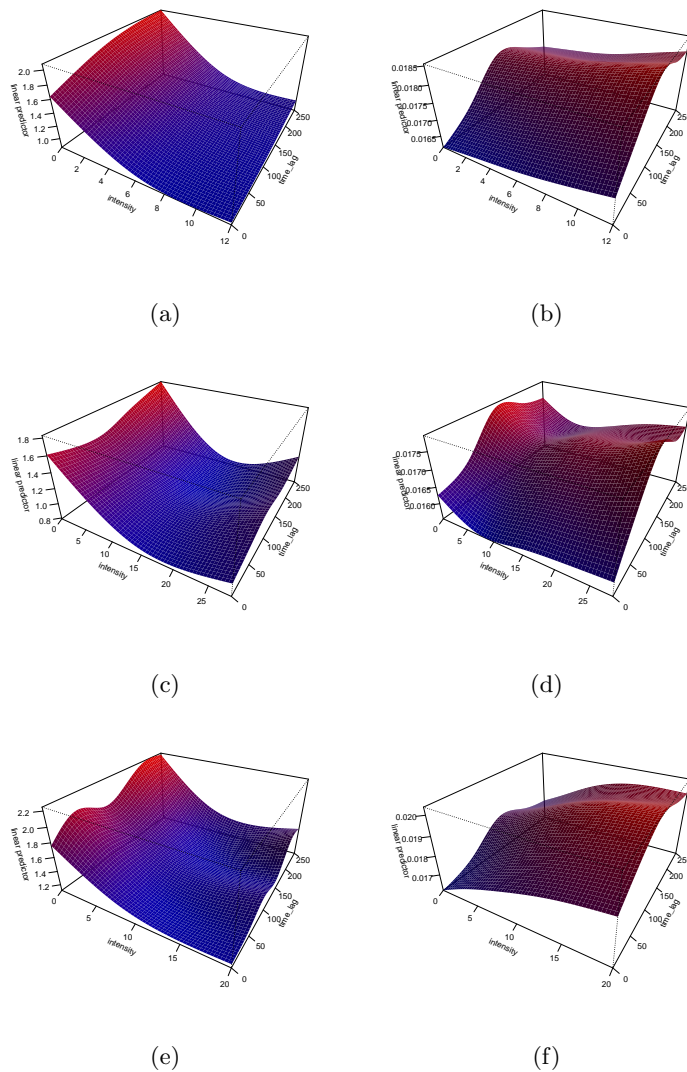


Figure 3.67: Policy effects of the consumption (upper row), investment (middle row), and technology subsidizing policy (lower row) on volatility (left column) and average growth rates (right column) for different initial conditions of the economy.

growth rate with the following GAM:

$$g = g_0 + te(\mu, T^{Pol}). \tag{3.56}$$

In Figure 3.67 we depict predictions for the business cycle volatility (left panels) and the average growth rate (right panels) for the three stabilization policies. One can see that especially the average growth rate varies substantially conditioned on different start states where apparently for start states that are lagged by 100 months the growth rate reaches a maximum. Nevertheless, the qualitative results regarding the effects of the three policies stay intact for both, the effect on the business cycle volatility and the average growth rate. As a result, the start state at which the policy is applied for the first time does not change the qualitative findings of our policy experiments. The policy results are then not only robust against the parametrization but also against the selection of initial start states from possible candidates generated by the pre-simulation.

3.6 Discussion and Conclusion

In this study we have analyzed three distinctive fiscal policies, each of them aiming at a stabilization of the economy during downturns. The first stabilization policy is a demand-oriented policy that provides consumption subsidies to households. The two other policies are supply-oriented policies that provide subsidies to firms in order to encourage them to carry out investments in physical capital. Thereby, the supply-oriented policies differ from each other in their technological alignment; while the one policy grants subsidies for any investment regardless its technological focus, the payout of subsidies is limited for the other policy to those investments that flow in the best practice technology. The choice of these policies has been motivated by real world examples of stabilization policies contained in economic stimulus packages enacted by the U.S. government during the recent economic crisis. In the Economic Stabilization Act of 2008, the U.S. administration provided tax rebates to households and investment subsidies to business firms, where the investment subsidizing was achieved by changing tax treatment rules for investment projects without deliberate steering effects. Besides an even bigger tax cut for households, several other measures contained in the American Recovery and Reinvestment Act of 2009 had a strong focus on supporting investments that generate sustainable growth by enhancing technological progress.

The goal of the policy analysis in this study has been to investigate the effectiveness of these three discretionary stabilization policies. In this context, we have addressed the following research questions: Are the three policies actually able to stabilize the economy? Do the policies have long-term effects on the economic performance? If so, do the long-term implications differ between the policies? And, finally, are the policies fiscally self-sustained so that they do not substantially change the level of government debt? While the first research question addresses the effectiveness of the policies with respect to their primary goal, the other questions address possible effects that may arise over time and can lead to conflicts of goals between short-term stability and other long-term economic goals. Besides of a possible conflict with the goal of sustainable government debts, those are especially conflicts between short-term stability and long-term growth, price stability and employment.

Our approach to address these questions has been to use a closed agent-based macroeconomic model in which each stabilization policy has been analyzed in an independent policy scenario. The agent-based model, which is an extension of the Eurace@Unibi model, is able to replicate a considerable number of empirical stylized facts. Furthermore, the model has the appealing property that it generates endogenous business cycles with realistic features, which makes the business cycle analysis independent from introducing exogenous shocks to generate economic fluctuations.

We have run extensive simulations of the policy scenarios and obtained robust results regarding the effectiveness of the stabilization policies. In particular, we have found that all three policies have similar effects on the business cycle volatility. The policies reduce the short-term fluctuations substantially where a higher reduction of the volatility can be achieved by increasing the policy intensity. As a result, there are only little differences between the policies regarding their common primary goal. Regarding possible growth effects, however, we have obtained a more ambiguous picture. The technology subsidizing policy has a strong growth-enhancing effect that is increasing in the policy intensity. The consumption subsidizing policy leads only to a slight improvement of the average growth rate, where the effect of this policy becomes also stronger with the intensity of the policy. In contrast, the investment

subsidizing policy leads to a reduction of economic growth that is not monotonic in the policy intensity; for this policy we could identify a critical policy intensity at which the policy has its greatest negative impact on the average growth rate. Altogether, these observations lead to a first striking conclusion: even if the policies are almost equal with respect to their effectiveness to smooth the business cycle, they differ regarding their implications for long-term growth substantially.

At the same time, the considered stabilization policies show substantial differences in their fiscal requirements and, therefore, have different implications for the accumulation of government debts. While the technology policy has almost no effect, we have shown that the two other policies, the investment subsidizing and the consumption subsidizing policy, lead to higher levels of public debt, where quantitatively the effect is stronger in case of the consumption policy. The policies also differ in their implications for price stability. The consumption policy leads to a strong increase of inflation, while the investment policy has a less pronounced effect and the technology subsidizing policy has almost no effect on inflation. Based on these observations, we can expand our conclusions by the following statement: regarding long-term effects on macroeconomic aggregates, the technology policy dominates the two other policies, where a second best policy cannot be determined without articulating relative preferences for long-term growth, fiscal sustainability and price stability.

We have explored the mechanisms underlying the different policy effects and shown that the heterogeneity of firms with respect to productivity is an important determinant for the differences of the emergent medium- and long-term effects. We have shown that especially in the period after the outset of the simulation, when the state of the economy is still almost equal between the scenarios, high- and low-tech firms react in different ways to the implementation of the policies. More precisely, depending on the type of policy, high-tech firms expand their output and low-tech firms reduce the output in response to the policies and vice versa. These reaction patterns result in short-term changes of the distribution of market shares and prices, but also in a relative shift of the labor demand between high- and low-tech firms. Sooner or later, the effects on the labor demand will change the size and composition of the supply side of the labor market, so that the short-term reaction of firms will also change the wage offers and, eventually, the total wage structure in the economy. These wage adjustments influence the cost structure and, therefore, the relative competitiveness of firms. This triggers corresponding adjustments of production strategies, which in turn launch further changes of prices, labor demand, wages and so forth. Altogether, the initially differing response of high- and low-tech firms triggers a complex interplay of wage, productivity, cost and output dynamics, which drives the different medium- and long-term effects of the stabilization policies. These non-linear dynamics illustrate the importance of the time horizon for the policy analysis. Furthermore, the exploration of mechanisms has shown that the heterogeneity of firms is not only an important determinant for the policies effects but also itself affected by the stabilization policies. This means, policies change the evolution of the distribution of firm sizes and productivity in the economy. We have shown that in the long run the heterogeneity with respect to firm size increases for the consumption and technology policy, but declines for the investment policy. Since a higher heterogeneity with respect to firm size is associated with a higher market concentration, these results suggest negative implications for the competition in the economy of the former policies and a positive implication for the competition of the latter policy.

What are the implications for the economic literature? The question whether stabilization policies have effects on long-term growth has been addressed especially by the endogenous growth literature with inconclusive results. Many studies have concluded possible effects by analyzing the effect of short-term fluctuations on long-term growth without explicitly considering stabilization policies in their analysis. Others have incorporated a (fiscal) stabilization policy, but focused on the automatic stabilizers income tax and unemployment payments without paying attention to a more elaborate design of discretionary stabilization policies. The endogenous growth literature has stressed the importance of structural factors of the models under consideration for the long-term effects of stabilization policies. Structural factors can thereby be the assumption regarding the mechanism generating endogenous growth (Schumpeterian models versus learning-by-doing hypothesis) or the source of shocks driving the short-term volatility (monetary versus real shocks). Our analysis suggests that besides those structural aspects also the concrete design of the policy plays an important role for long-term effects of stabilization policies. In that sense, maybe the wrong question has been posed in the literature. Given our findings, the question should not be *whether* stabilization policies foster or reduce long-term growth, the question should be *which* stabilization policies foster or reduce long-term growth.

The results obtained from our policy analysis have also strong implications for policymakers. In general, policymakers can choose from a wide variety of different discretionary policy measures to alleviate an economic downturn. Our policy experiments suggest that different policy opportunities may have different consequences for the economic development in the medium and long run, even if they can equally stabilize the economy in the short run. For our policy examples, we have shown that there is no ideal policy, all three are associated with at least one conflict of goals between short-term stability and long-term economic parameters. However, a policy that supports the speed of technological change seems to be the best choice as it leads to sustainable long-term growth and at the same time to almost no additional government debts and to stable prices. The only negative aspect of this policy is its long-term impact on the market concentration. Unlike for the technology policy, we have found more serious conflicts of goals for consumption subsidizing and untargeted investment subsidizing policies. The most striking one can be found for the case of investment subsidization; if the government grants subsidies for any investment without technological targeting, then the short-term stabilization leads to a reduction of long-term growth. For consumption subsidizing policies, one can find conflicts especially between short-term stability and the long-term goals of price and fiscal stability rather than the classical trade-off between smoothing of short-term volatility and long-term growth. In that sense, the policy measures contained in the U.S. stimulus package of 2009 with their technology-oriented targeting could be considered as a more appropriate choice for a farsighted stabilization policy. Such a policy would have potential to bring the U.S. economy not only back on its pre-crisis output level but also at a higher long-term growth path. Nevertheless, policymakers should be aware of the fact that any stabilization policy comes at a price. It is then the job of policymakers to carefully assess possible long-term effects of their candidate policies and to rate which of the possible negative consequences have higher or lower priorities.

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