Cohesion Policy and Inequality Dynamics: Insights from a Heterogeneous Agents Macroeconomic Model

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Abstract

Regions within the European Union differ substantially not only with respect to per capita GDP, but also with respect to income inequality within the regions. This paper studies the effects of different types of technology-oriented cohesion policies, aiming at the reduction of regional differences, on the convergence of regions and the dynamics of income inequality within regions. In particular, policies are analyzed using a two-region agent-based macroeconomic model – the Eurace@Unibi model – where firms in the lagging region receive subsidies for investment in physical capital. It is demonstrated that the short-, medium- and long-term effects of the policies on per-capita output and between- as well as within-regional inequality differ substantially. Effects depend on how successful the policy is in incentivizing firms to choose best available capital vintages and on how flexible labor markets are in the targeted region.

Keywords: cohesion policies, technology adoption, agent-based model, inequality, heterogeneity
JEL Classification: C63, O33

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1 Introduction

There is considerable inequality in terms of per capita income between European Union members states. Countries from Central Eastern Europe and Southern Europe are facing substantially lower per capita incomes than those from Western and Northern Europe. Moreover, we do not only observe income gaps between countries but unequally distributed incomes within countries.[1] Inter- as well as intra-regional inequality contributed to a questioning of the European integration project and also has put governments of single countries under pressure. Policymakers are striving for measures to alleviate these problems and a major pillar for fostering convergence of regions has been the European Regional Development Funds (ERDF). Empirically, however, the effectiveness of cohesion policy measures is contested, with recent evidence pointing towards the important role of the institutional set-up of the recipients to make these policies work (Becker et al., 2013).

Since the eastern enlargement of the EU also the countries from Central Eastern Europe have access to these policy measures. These countries lag behind the Western European countries in terms of their per capita incomes. Moreover, in these countries income inequality seems to have increased since the fall of the iron curtain. Besides, Eastern European countries differ from the old member states in various other respects that may be important for the effectiveness of the cohesion policies. In particular, with respect to their labor markets, it seems that a higher pressure is put on the unemployed to accept job offers[2] and higher efforts seem to go into the activation of the unemployed (OECD, 2007). Also, the absorptive capacity to turn the transfers in per capita growth may differ in these countries from the old European countries due to a lack of human capital in the workforce.

In this paper, we analyze to which extent technology-oriented cohesion policies can help fostering convergence of per-capita incomes between regions and how they affect intra-regional income inequality. We analyze the outcomes of the technology policies on convergence and income inequality with respect to the flexibility of the labor market in the region receiving the transfers and the targeted region's absorptive capacity. Furthermore, we examine how the effectiveness of a technology-oriented policy is affected by the actual design of the policy. In particular, we compare policies that are able to incentivize firms to purchase technologies on the frontier with such that support investments regardless of the chosen technology level.

The analysis is done within a multi-regional version of the Eurace@Unibi agent-based macroeconomic model. We believe that an agent-based macroeconomic model is the most appropriate tool to gain insights into the emergent dynamics of average per capita incomes and the income distributions in these regions. The focus on implications of the policy on income inequality requires an approach able to capture the evolution of heterogeneities within households and firms in a region. Recent empirical work highlights

[1] For more details, see our discussion in Section 3.

[2] New EU member states tend to have lower replacement rates than in Western European countries (van Vliet and Caminada, 2012)

the importance of heterogeneity of firms for the explanation of income inequality in a region (Faggio et al., 2010). Moreover, existing empirical evidence on the effect of labor market institutions on income inequality has been contested, mainly for inappropriateness of econometric models and alternative approaches from artificial sciences have been called for (Freeman, 2008).

A crucial feature of the Eurace@Unibi model is that it captures the complementarity between the quality of physical capital and specific skills of the workforce in determining a firm's productivity. This feature in combination with the endogenous vintage choice of firms and the fact that workers' specific skills evolve through on-the-job-learning, which depends on the quality of the employer's physical capital, gives rise to endogenously emerging heterogeneity in productivity across firms within a region. It also leads to persistent differences in productivity distributions and growth rates between the two regions. The approach seems well able to capture the effect of different policies on income inequality (among workers) within regions and between regions, which is hard to do in dynamic equilibrium models based on assumptions of representative agents.

Within this framework we explore the implications of policies which resemble measures implemented within the European Regional Development Fund (ERDF). The ERDF aims at strengthening economic and social cohesion in the European Union.[3] Technology policies are a major pillar of the ERDF that, by subsidizing firms' investments, try to move countries closer to the technological frontier. In particular, the program tries to foster investment of firms in advanced technologies in the target region, thereby improving the average quality of the physical capital stock.[4] Empirical evidence for a success of the directed measures, in the sense of an improvement of the average quality of the firms' physical capital is, however, missing.

Taking a calibrated version of our model as a starting point, we apply technology-oriented policies to the lagging low-tech region under different scenarios of labor market flexibility. We are able to identify a set of results with respect to the convergence of regions and the effect on between and within regional income distribution. Moreover, the technology policies that are analyzed are differentiated along their effectiveness in incentivizing firms to actually purchase investment goods from the technological frontier. We refer to a policy as *non-directed* if it provides investing firms with subsidies, but does not influence their technology choice. We label policies as *directed* if they affect the decisions of a certain fraction of firms in a way that it increases their incentives to acquire vintages at the technological frontier. Our main findings are summarized in Table 1. They show that the technology policy needs to be directed in order to foster

[3] In total the ERDF had a budget of Euro 201bn for the period between 2007-2013. As all these programs are matching funds the actual amount spent has to be doubled.

[4] For illustrative purposes we sketch an example highlighting what we have in mind when analyzing policies in our agent-based macroeconomic model. Here, a Portuguese firm with about 500 employees received investment subsidies to improve on the quality of its capital stock. The firm extracts ore and produces copper, lead and zinc concentrates. With the funds it modernized its infrastructure to boost extraction of copper ore by constructing new galleries to expand access to the ore, and upgraded the plant's processing operations that included facilities to wash the rock, treat and recycle water, and process waste material. Source: `http://ec.europa.eu/regional_policy/en/projects/portugal/turning-copper-to-gold`

	Inflexible labor market in R2	*Flexible labor market in R2*
Directed policy	Effect on output is positive for the overall economy, positive in R2, negative in R1; inequality in the economy is reduced, reduced in R2, increased in R1.	Effects on output are similar to inflexible labor market in R1 but substantially stronger in R2; overall inequality reduced, but inequality in region 1 is increased.
Non-directed policy	Effect on output is positive in both regions, but very weak; inequality in the economy is reduced, reduced in R1, no significant effect in R2.	Effects on output are similar to inflexible labor market in R1 but substantially stronger in R2; overall inequality and also inequality within both regions is reduced (effect much weaker in R1 than in R2).

Table 1: Summary of the main findings of the policy analysis. R1 refers to the high-tech region, R2 to the low-tech region.

convergence. Furthermore, such directed policies are also able to reduce the inequality within the target region.

We will turn to an in-depth analysis of the economic mechanisms underlying these findings in Sections 5.3 - 5.5. The main intuition for the observed policy effects is that in the framework of our model the high-tech region is characterized by a concentration of the (endogenous) distribution of firm technologies in the vicinity of the technological frontier, whereas in the lagging region this distribution is further spread out reaching also well below that frontier. This stronger heterogeneity of firms in the lagging region does not only correspond to larger wage inequality but also to a stronger heterogeneity of workers' reservation wages making it difficult for firms in the lower part of the technology distribution to expand their labor force. Therefore, policies, like non-directed subsidies or demand-oriented measures, in the lagging region, which aim to foster investment and expansion of output of firms in the lagging region without incentivizing them to move their technology closer to the frontier, result in an increase of rationing of firms on the labor market and associated upward pressure of labor costs. This reduces the competitiveness of firms in the lagging region and makes such policies relatively ineffective. Hence, to be effective it is crucial that a policy is able to influence the technology choice of firms in the target region, thereby bringing them closer to the technological frontier.

In the following section we relate our work to the existing literature. In Section 3 we will outlay what, as we argue, are some of the characterizing features of European economies with respect to convergence and income inequality. The following Section 4 introduces the model. Section 5 starts with a description and motivation of the policy treatments. We continue by showing and analyzing the simulation output for a baseline model without policy intervention to which we then relate the effects arising from the policy analysis. Section 6 concludes. The Appendix contains a detailed description of our baseline parameter setting, a documentation of comprehensive robustness checks and a systematic list of the empirical stylized facts which have been reproduced using the Eurace@Unibi model. An Online-Appendix of the paper contains a guide for the reproduction of the simulation results presented in this paper. A Virtual Appliance containing an implementation of the model as well as fully installed graphical user interfaces and tools for statistical analysis and graphical illustration of simulation data is provided on a dedicated webpage[5] in order to allow such reproduction and also alternative experiments.

2 Literature Review

Our work is related to several streams of literature. The most important ones are (i) the work on the relationship between inequality and growth, (ii) the (mostly empirical) analyses of the effectiveness of European cohesion policies, and (iii) the literature on agent-based macroeconomic modeling.

The literature on the relationship between inequality and growth dates back to Kuznets (1955), who argued for an inverted U-shaped relationship, and by now is very rich and diversified. The focus in our paper is on income inequality within a population of (skill differentiated) production workers and the relationship between the evolution of this type of inequality and the growth rate of a region. The main source for inequality in our setting is the endogenously arising heterogeneity of the quality of firms' capital in combination with the workers skills. Hence, the vivid discussion in the literature about reasons for a rising gap between the top 1% (or top 0.01%) and the rest of the income or wealth distribution, (e.g. Atkinson et al., 2011), or about the role of remuneration schemes in this development (e.g. Lemieux et al., 2009), as well as issues of functional inequality, which has been the focus in the framework of other agent-based (e.g. Dosi et al., 2013) or heterodox (e.g. Dutt, 2016) growth models, are outside the scope of our analysis.

By focusing on the matching of (heterogeneous) workers with different types of technologies characterized by different productivities as an important driver of (wage) inequality, our approach is related to Aghion (2002) and Aghion et al. (2002) who study in the framework of a Schumpeterian growth model how the persistent arrival of new machine vintages affects growth and wage inequality if workers cannot fully transfer their experience across vintages. A main finding in Aghion (2002) is that the wage inequality, measured as the ratio between maximal and minimal wage in the economy in the stationary equilibrium, is positively related to the growth rate. It should be noted that in the setting of these papers, which rely on an OLG structure with a life-span of two periods for each firm and assume that each new firm always uses the latest vintage, the rate of growth is strongly positively linked to the heterogeneity of productivity across firms. Our approach, which incorporates endogenous technology choices of firms and therefore generates endogenous cross firm productivity distributions, does not exhibit

[5] `http://www.wiwi.uni-bielefeld.de/lehrbereiche/vwl/etace/Eurace_Unibi/Virtual_Appliance`

such a positive linkage between growth rate and firm heterogeneity. While our model shares the property of the Aghion (2002) and Aghion et al. (2002) models that wage inequality is positively linked to cross firm heterogeneity with respect to the technology level, in our analysis the region with higher growth rate is characterized by a lower technological heterogeneity compared to the lagging region and therefore also exhibits lower wage inequality.

The endogenous determination of the vintage structure of the individual firms as well as the aggregation of these structures across heterogeneous firms is a property of our model which distinguishes it from the endogenous growth models addressing the linkage between growth and inequality. This holds, in particular, for the consideration of the effect of the skills endowment in the firms' labor force on the firm's technology choice. In this respect our approach is somehow related to Caselli and Coleman (2006) who analyze the implications of a similar mechanism on a country level in order to understand cross country technology differences.[6] As our model produces persistent growth differences between regions it is also related to work like Howitt and Mayer-Foulkes (2005), dealing with the emergence of convergence clubs. Whereas in Howitt and Mayer-Foulkes (2005) the key mechanism driving the divergent dynamics between regions is the positive dependence between the aggregate productivity in a region and the effort in skill formation of local entrepreneurs, in our setting it is the positive relationship between technology choice and workers skill dynamics on the firm level. Hence our setting allows to study the effects of policies which (potentially) influence the firms technology choice.

The link between inequality and growth has also been studied intensively from the perspective of the role of human capital formation. In particular, the literature in development economics, incorporating endogenous individual investment in human capital under financial constraints, argues that for developed economies growth is negatively affected by large inequality since it reduces overall investment in human capital (see, e.g., Galor and Moav, 2004). This channel is absent in our setting, since we take the general skill distribution in each region as given and assume that specific skills are acquired due to on-the-job learning. In this respect, our work is related to contributions, which have shown that also in frameworks with only physical investments inequality negatively affects growth in the presence of learning-by-doing effects and imperfect capital markets (see Aghion et al., 1999). However, differently from these approaches, which model the learning-by-doing effect on an aggregate level, our approach captures the effects of firm heterogeneity on skill distribution by modeling the adjustment of individual worker skills, which depend on the technology level of the employer. In our setup there is no distinction between different tasks and the capital labor ratio is assumed to be constant and identical across all capital vintages and skill levels. Hence, the model does not capture employment polarization in a sense that technological change might foster the substitu-

[6]Clearly, this type of mechanism is also related to the concept of 'directed technological change' (Acemoglu, 2002), however, contrary to this literature we are concerned with the diffusion of technologies rather than the evolution of the technological frontier and the difference in the *distribution* of firms' and workers' properties across regions.

tion of labor by capital for certain (routinized) tasks, as it is assumed in the polarization literature (see Autor and Dorn, 2013). Hence, also the typical channel, induced by polarization, through which technological change leads to an increase in wage inequality, is not present in our model.

Firms in our setting face potential financial constraints, and hence the ability to carry out planned investments close to the frontier technologies is affected by firms' savings. Therefore, the channel, identified e.g. in Matsuyama (2000, 2002), that wealth concentration allows some investors to realize high-return and high-cost projects thereby positively affecting growth is relevant in our setting with respect to the distribution of firm savings (rather than individual income or wealth).

Finally, it should be mentioned that in our analysis the institutional setup as well as the fiscal policy design in the considered regions is assumed to be constant and exogenously given. Hence, we abstract from any potential impact of inequality on the evolution of these aspects of the economy. Work e.g. by Persson and Tabellini (1994) or Acemoglu et al. (2011) indicates that endogenizing such institutional aspects should contribute to a negative relationship between inequality and growth.

Previously, empirical studies on the link between inequality and growth have relied on cross-country growth regressions with inequality as an explanatory variable (see, e.g., Campano and Salvatore, 2006, for a survey). All these studies have provided a fairly robust body of evidence in favor of a negative relationship between income inequality and growth. As better and more encompassing data on income distributions has become available, however, evidence seems to have shifted suggesting that a more refined view is needed specifying which type of inequality and also which time-frame is considered (de Dominicis et al., 2008). For example, Halter et al. (2014) show that high inequality seems to have positive growth implications in the short run, whereas the empirical evidence points towards a negative long run relationship. Using data from industrialized countries Voitchovsky (2005) establishes that increased inequality in the lower part of the income distribution has a negative impact on growth whereas a positive relationship seems to exist at the upper end of the distribution. These empirical findings are very relevant for our analysis since our baseline simulation results capture the (long-run) differences in growth and inequality between structurally different regions and our model picks up only inequality across 'regular workers' rather than the upper end of the income distribution.

In light of this discussion of the literature, the main contribution of this paper from a modeling perspective is to rely on an approach, which, within a closed macroeconomic framework, captures the co-evolution of the distribution of the technology levels of firms and the skills of workers. This is accomplished by modeling the interaction of technology adoption of individual firms and learning processes of workers to run these technologies. The approach allows us to gain insights on the channel through which firm heterogeneity relates to inequality and growth, and more importantly in light of the policy focus of this paper, it also allows to capture how policies affect behavior of firms in different parts of the productivity distribution. Introspection of such a channel requires heterogeneous agents on the firm and worker side which is typically beyond standard economic frameworks. Furthermore, the theoretical insights reviewed above typically rely on the analysis of long-run equilibria. Considering equilibrium dynamics and thereby assuming that all firms and workers base their technology and employer choice decisions on rational expectations about the future dynamics of technology and skill distributions, seems very strong. In the agent-based framework we propose here, no such strong assumptions are made, but choices are based on limited foresight of agents and finite planing horizons. Furthermore, our approach allows to distinguish between short-, medium- and long-run effects of policies.

Empirical work on the effectiveness of European cohesion policies finds mixed results.[7] Studies taking a national perspective, such as Beugelsdijk and Eijffinger (2005) detect 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 and provide evidence for overspending to some regions (Becker et al., 2012). Very importantly in our context, in a follow up, Becker et al. (2013) show that only regions with sufficient human capital and good-enough institutions are able to turn the transfers into higher per capita income growth and investment. This evidence is well in accordance with theoretical arguments highlighting the importance of the local absorptive capacity for growth in a region (see Aghion and Javarel, 2015).

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. We believe that our simulation based approach to evaluating these policies is complementary to these empirical studies. It allows us to look into the effectiveness of policies under different time-horizons, let us analyze outcome variables for which data very often does not exist, and perhaps, most importantly, allows for an investigation of the economic mechanisms underlying the policy outcomes. Finally, we can carry out counter factual policy experiments, thereby evaluating policy proposals without actually implementing them.

In the last ten years a number of closed macroeconomic models using an agent-based approach have been developed (see, e.g., Gintis, 2007; Dosi et al., 2010; Delli Gatti et al., 2010; Ashraf et al., 2017; Raberto et al., 2012; Wolf et al., 2013). Several of these agent-based macroeconomic models have shown the importance of the approach

[7] A large literature has studied convergence between countries or between regions without focusing on the effects of particular policies. A review of this literature can be found e.g. in Islam (2003).

for economic policy design, see e.g. Dawid and Neugart (2011) or Fagiolo and Roventini (2017) for general discussions of this point. Closely related to this work are Dawid et al. (2012a), analyzing the effect of labor market integration policies on the convergence of regions, and Dawid et al. (2014) comparing the effectiveness of human capital and technology policies as instruments of cohesion policy. Dosi et al. (2010) have looked 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 polices. In Dosi et al. (2015) they address the appropriateness of various monetary and fiscal policy mixes to combat the European economic crisis and in Dosi et al. (2013) it is studied how the level of (functional) inequality affects the effectiveness of different types of policies. The emergence and effect of inequality in an agent-based setting with endogenous growth and hierarchical firms is studied in Ciarli et al. (2012) and Riccetti et al. (2016) employ an agent-based macro model to analyze the effect of consumer credit on inequality. Directly related to our work are also Seppecher (2012), Napoletano et al. (2012) and Dosi et al. (2017) which study the implications of increased labor market flexibility using an agent-based approach. However, it should be noted that in our framework labor market flexibility refers to the speed by which unemployed workers adjust their reservation wage, while in the afore-mentioned contributions the focus is on a change in minimum wages or the effects of different types of linkages between the wage level and business cycle indicators. Contrary to these papers the effect of labor market flexibility on the technology choice of firms is a main driver of our results.

A distinctive feature of our approach relative to existing agent-based macroeconomic models is that it jointly features a spatial dimension and technology adoption by firms which is complementary to an evolving stock of specific skills within a firm.

3 Inequality and Convergence in Europe

To which extent did European economies converge and how has income inequality evolved in these countries? We try to investigate this question by descriptively analyzing per capita incomes for 24 countries of the European Union.[8] In 1989 the iron curtain started to fall. Eventually it implied that economies became more integrated. Product markets opened up and firms' access in lagging countries to latest technologies improved significantly. Thus, the mid nineties may be a good starting point to look into economic convergence of the countries having been on one or the other side of the iron curtain.

Sorting countries along their GDP per capita in the early nineties, it turns out that Austria, Belgium, Denmark, Germany, The Netherlands, and Sweden made up the upper quartile with an average per capita income in US dollars (as of 2005 prices) of about 28.000 (see Figure 3 panel (a)). In these countries per capita income steadily increased

[8]We excluded four of the 28 members of the EU for the following reasons. Data on Croatia for the first years of the 90's is not available as it fought a war of secession with former Yugoslavia after having declared independence in 1991. Luxemburg has been excluded from the analysis as it constitutes an outlier, possibly because of its peculiar tax policy to attract foreign capital. Finally, no GDP data is available for Latvia and Lithuania for the year 1990.

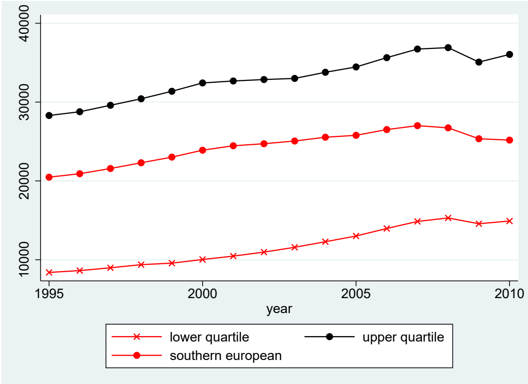
since then to an average of about 36.000 US dollars in the year 2009. Countries in the lower quartile of the per capita income distribution (as of the beginning of the 1990ies) which happen to be all countries from the other side of the iron curtain (Bulgaria , Estonia, Hungary, Poland, Romania, and Slovakia) had an average per capita income of less than 10.000 US dollar. These countries grew in the upcoming 15 years but could by no means close or even diminish the gap with respect to the countries at the frontier. A third group of countries from Southern Europe (Greece, Italy, Portugal and Spain), in which we are mainly interested here because they feature less flexible labor markets as compared to the rest of the European countries, exhibit per capita incomes somewhere in the middle of the other two groups. Again, we do not observe a catching up process to the frontier.

How did these groups of economies fare in terms of income inequality? Panel (b) of Figure 3 gives some insight in this respect.[9] High income countries had rather stable income distributions with Gini coefficients of slightly more than 0.25. Throughout the considered time period the Gini coefficients for the country groups with low per capita incomes indicate a much more unequal distribution compared to the high income countries. The countries from Southern Europe, which combine a per capita income between the other two groups with inflexible labor markets, feature income distributions with even higher inequality than the low income countries.

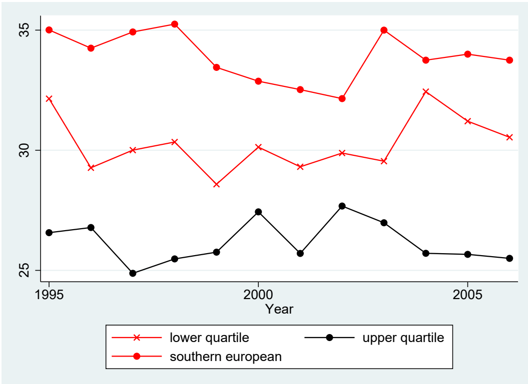
In accordance with these stylized facts, we will present an agent-based macroeconomic model which (in the absence of policies) produces dynamics in which a technologically advanced region is characterized by larger per-capita output and smaller inequality compared to a less developed region. Our agent-based model features a range of intermediate variables that will help us to better understand the mechanisms that underlie our explanation. To some extent these intermediate variables have closely connected empirical counterparts. One such important driver of the observed behavior in our agent-based model, as we will explain in more detail later on, is the change in the relative size of unit labor costs in the two regions. Panel (c) of Figure 3 highlights that these costs have actually been converging from the mid nineties onwards for the three country groups under consideration. While this piece of evidence is in line with the general mechanisms of our model (see Section 5.2), a more detailed *empirical* analysis of the mechanisms responsible for the results is beyond the scope of this paper, mainly because meaningful indicators against which our model could be benchmarked are largely lacking.

The main agenda of this paper is to rely on a model-based policy analysis to study how subsidy schemes for firms' investments affect the convergence of regions and the within regional income distribution.

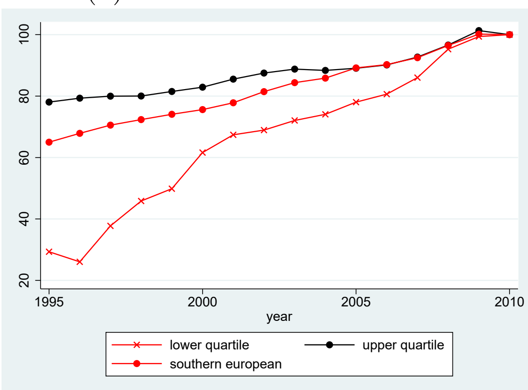
[9] We restrict ourselves to data based on disposable income because it covers for the countries under investigation here the largest time span. The calculation of the means of the Gini coefficients for the three groups of countries excludes Romania as no comparable data occurs to be available.



(a) Mean GDP per capita



(b) Mean of Gini coefficients



(c) Mean of unit labor costs

Figure 1: (a) Mean GDP per capita at 2005 constant prices (US dollars) of European countries in upper and lower quartile of GDP per capita distribution as of the beginning of the 1990ies, and for Southern European countries. Data source: Penn World Tables; (b) Mean of Gini coefficients based on disposable income of countries in upper and lower quartile of GDP per capita distribution (as of the beginning of the 1990ies), and for Southern European countries. Data source: World Income Inequality Database, United Nations University – WIDER World Institute for Development Economics Research; (c) Mean of nominal unit labor costs per hour (2010=100). Data source: Eurostat; countries included in upper quartile are Austria, Belgium, Denmark, Germany, Netherlands, and Sweden; countries included in lower quartile are Bulgaria, Estonia, Hungary, Poland, Romania (not in mean for Gini), and Slovakia; Southern European countries are Greece, Italy, Portugal, and Spain.

4 The Model

4.1 Overall Structure

The Eurace@Unibi model describes an economy with an investment and a consumption goods sector, and a labor, 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 horizontally differentiated versions of 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. (2017). The following short treatment of the model has been presented in similar form already in Dawid et al. (2012a, 2014), where the Eurace@Unibi model has been used for analyses of policy issues different from the one we are focusing on here.

Capital goods of different quality are provided by a capital goods producer 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 different vintages of capital goods combined with labor as inputs to produce a single type consumption good with horizontal differentiation across firms. Households have idiosyncratic preferences for properties of the goods offered by the different producers which are not explicitly modelled. 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. This choice is driven by the comparison between the prices of the available vintages and their expected returns for the firm which depend on the skills of the firm's workforce. The capital good producer charges different prices for the different vintages based on the estimated value of the vintages for the consumption good firms. Consumption goods offered by the different firms are horizontally differentiated. They 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 a single asset are traded, namely an index share 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 shares. The dividend paid by each index 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 loose 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 in the same region.

Each government collects income and profit taxes from the local households and firms and pays unemployment benefits. Furthermore the two local governments finance the union-wide cohesion policy. The regional governments run a balanced budget by adjusting the tax rates in a way that, retrospectively, the tax rates would have balanced the government expenditures over a given time period in the past.

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, because it is assumed that workers accept jobs only inside 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, financial and labor markets. While empirical evidence on EU trade, foreign direct investments, or indicators on transposed internal market directives (see European Commission, 2012) suggests that integration of those markets has proceeded to a very large degree, there is evidence that labor mobility in Europe is still low.[10]

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

[10] In 2010, only 2.8% of working-age European citizens lived in another EU member state (see European Commission, 2011).

the corresponding management literature. A more extensive discussion of the Management Science approach can be found in Dawid and Harting (2012).

Agents' 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.

4.2 Agents, Markets, and Decisions

4.2.1 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 $v = 1, ..., V_t$, where V_t denotes the number of available vintages a time t. The accumulation of physical capital by a consumption goods producer follows

$$K^v_{i,t+1} = (1-\delta)K^v_{i,t} + I^v_{i,t} \tag{1}$$

where δ is the depreciation rate and $I^v_{i,t} \geq 0$ 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 capital 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

$$Q_{i,t} = \sum_{v=1}^{V_t} \min\left[K^v_{i,t}, \max\left[0, L_{i,t} - \sum_{k=v+1}^{V_t} K^k_{i,t}\right]\right] \cdot \min\left[A^v, B_{i,t}\right], \tag{2}$$

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 4.2.3. 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 4.2.4).

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. The firm might be rationed on the labor and credit market, in which case it adjusts its production quantity downwards.

4.2.2 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.

4.2.3 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:[11]

$$b_{h,t+1} = b_{h,t} + \chi(b_h^{gen}) \cdot \max[0, A_{i,t} - b_{h,t}]. \quad (3)$$

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 $0 < \chi(b_h^{gen}) < 1$. 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.

4.2.4 Technological Change

The supply of the capital goods and the process of technological change is modeled in a very simplified way. We recur to a single capital good producer that offers different vintages of the capital good $v = 1, ..., V_t$ 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 Subsection 4.2.6), 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):

$$p_{v,t} = (1 - \lambda)p_t^{cost} + \lambda p_{v,t}^{value}. \quad (4)$$

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.

[11] Similar formulations have been widely used in the literature building on the seminal work by Nelson and Phelps (1962).

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 modelling 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.

4.2.5 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 (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.

Capital 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 capital good producer keeps on delivering also older vintages as the technology frontier grows. Note, that the way we model the capital 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 capital goods. Having an elaborated vintage supply is crucial for our contribution 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.

4.2.6 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 $\overline{v} > 0$ the firm raises the base wage offer by a fraction φ to attract more workers, i.e.

$$w_{i,t+1}^{base} = (1 + \varphi) w_{i,t}^{base}. \tag{5}$$

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

$$w_{i,t,g}^{O} = w_{i,t}^{base} \times \min[A_{i,t} \bar{B}_{i,t-1,g}] \tag{6}$$

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 for the determination of wage offers is that firms can observe general but not specific skills of job applicants. Moreover, our firms are aware that due to on-the-job learning specific skills of a worker with certain general skills will soon catch-up to that of the firm's present employees with that general skill level. Therefore, they use the average specific skills of all employees with general skill g in their own firm in order to estimate the specific skills of an applicant with general skill level g. 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 upshot of our wage setting rule is, furthermore, that in our model wages follow productivity.[12]

An unemployed worker considers the wage offers posted by a random sample of searching firms in the worker's region and compares them with her reservation wage $w_{h,t}^{R}$. A worker h with general skills g only applies to firm i if it makes a wage offer $w_{i,t,g}^{O} > w_{h,t}^{R}$.

[12] Several studies have examined from an empirical perspective how closely wages follow productivity, including analyses that try to explain movements in the labor share, see, e.g. Autor et al. (2017). While there is some evidence on a decoupling of productivity and real average compensation presented in Schwellnus et al. (2017) for the years from 1995 to 2013 for 24 OECD countries, the result seems to be somewhat sensitive to the way how wages are measured. Meager and Speckesser (2011), for example, assert, based on data from 25 countries for 1995-2009, that wages follow productivity when they are measured as total compensation. Our own empirical analysis (not presented here) based on Eurostat data for the three country groups considered above also suggests that the simplified wage-setting rule implemented in our model occurs to be an appropriate modeling choice.

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 her 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 she accepts the job offer with the highest wage offer. In case she does not receive any job offers she 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.

4.2.7 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 Carroll, 1997; Allen and Carroll, 2001) which assumes liquidity constrained consumers facing risky incomes who, therefore, desire a buffer stock equal to a certain number of monthly incomes:

$$C^{exp}_{h,t} = I^{Mean}_{h,t} + \kappa(W_{h,t} - \Phi \cdot I^{Mean}_{h,t}) \tag{7}$$

where $I^{Mean}_{h,t}$ is the mean individual income of an agent over the last T periods and the parameter Φ is the target wealth/income ratio. The parameter κ indicates how sensitive consumption reacts to deviations from the target level.

At the beginning of their shopping procedure households 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). Specifically, it is assumed that the value v_h of a consumption good i for a household h is a function of the price $p_{i,t}$. Then, the consumer selects a good i from all available goods at time t with probability

$$Prob_{h,i,t} = \frac{exp(-\gamma^C v_h(p_{i,t}))}{\sum_{i'} exp(-\gamma^C v_h(p_{i',t}))}. \tag{8}$$

The parameter denoted as γ^C governs the price sensitivity of consumers and therefore the intensity of competition between the consumption good producers. In essence, the model captures the idea that the single type consumption good is horizontally differentiated across firms. Households have idiosyncratic preferences for properties of the goods offered by the different produces which are, however, not explicitly modelled. 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 horizontally differentiated 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. These households have the opportunity to spend the remaining budget for another good in a second shopping loop. In this case the 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.

4.3 Parametrization and Validation

In order to determine the values and ranges of parameters to be used in the policy experiments we follow an approach that combines direct estimation of parameters for which empirical observations are available with an indirect calibration approach. This is done in order to establish confidence in the ability of the model to capture economic mechanisms which are relevant for real world economic dynamics. 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. Table 4 in Appendix A summarizes the most relevant parameters and the accompanying text justifies the chosen values citing the sources from which they were derived. 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 microfoundations for modeled behavior.

A large set of stylized facts on different levels of aggregation has been reproduced by the Eurace@Unibi model. Table 5 in Appendix C provides a summary of these stylized facts and the corresponding references. In addition to this, the next section will show that the calibrated version of the model does not only qualitatively reproduce the empirical patterns of the evolution and the relative size of per capita output in different types of economies shown in Figure 3 (a), but also the patterns of income inequality measured by the Gini coefficient as depicted in Figure 3 (b). In particular, the model not only reproduces that low-technology regions have lower per-capita output and higher Gini coefficients than high-technology regions. It also reproduces the observation that the regions with relatively inflexible labor markets are characterized by larger income inequality compared to the low-tech regions with flexible labor markets, although their per capita output is higher. All these stylized facts have been reproduced although

Table 2: Initialization of capital stock and skills

	Region 1: high-tech	Region 2: 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

they have not been targeted in the calibration, and the parameter setting has not been adjusted from the default setting described above.

5 Policy Analysis

5.1 Experimental Set-up

Our policy experiments are addressing convergence between an advanced and a lagging region (country), and the evolution of the distribution of income within a region in a two-region version of the model described above. Table 2 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. This setting is supposed to capture in a very simple way that on average workers in the high-tech region 1 adjust faster to an increase in the quality of the physical capital they are working with than workers in region 2.[13]

The technological frontier at $t = 0$ is set to a quality of 1.7 and afterward grows at an annual rate of 1.8 percent. Firms in both regions may purchase a capital good of that quality, i.e. capital goods markets are integrated from the beginning of the simulation. The same holds for the consumption goods markets.

Within this setup we mimic the European Union technology policies by introducing a subsidy for investments of firms in the target region R2. The subsidy covers 20% of the expenses of firms in region 2 for the purchase of the new physical capital. In particular, we consider in our experiments four different variations of technology policies, which

[13] For a quantitative assessment of the distance of various Eastern and Western European countries to the world technological frontier see Growiec (2008). The initial productivity ratio of 0.66 between the low and the high tech region is loosely based on a comparison of TFP estimations for countries in the upper and lower quartile groups reported (for the year 2007) in Beugelsdijk et al. (2017). In order to measure the educational quality of the working-age population one may recur to findings of the International Adult Literacy Survey (IALS) as, e.g., documented in Barro and Lee (2001). There it is reported that Eastern European countries scored on average lower in work related skills in the adult population in the mid nineties than Western European and, in particular, Northern European countries. Recent evidence (e.g. OECD, 2016, Figure 2.22) suggests that this gap is still substantial and seems very persistent, which is in accordance with our assumption that the difference in general skill distributions across regions stays constant over time.

differ with respect to their influence on the technology choice of the firms in region 2 receiving the subsidy.

We define by $0 \leq \alpha \leq 1$ the fraction of firms in region 2 which receive a subsidy under the policy only if acquiring the latest vintage directly on the frontier. A fraction $1 - \alpha$ of firms in region 2 receive the subsidy regardless of their technology choice. Firms know whether they need to invest on the frontier in order to receive the subsidy and take this into account when applying their vintage choice rule. In the experiments we consider the values $\alpha = 0$, which is denoted as non-directed technology policy, as well as the cases $\alpha = 0.1$, 0.2, and 0.3, corresponding to an increase in the direct influence of the policy on the firms' vintage choice.

The reason to consider these different policy variations is twofold. First, even if the policymaker's intention is to only subsidize firm's investments in the lagging region if they are of the high quality vintage type, it is in general difficult for the policymaker to determine what is exactly the frontier technology for a given firm. This makes the enforcement of the highest vintage constraint problematic and it is important to understand how crucial it is for the effect of the policy if no perfect enforcement is possible. The experimental set-up may be seen in relation to the literature that studies the role of absorptive capacity for the effectiveness of transfers. While this line of investigation has been playing a prominent role in the evaluation of aid policies (Burnside and Dollar, 2000), it has become of interest in the context of analyzing the effectiveness of EU funds only recently (see, e.g., Becker et al., 2013). Second, a-priori it is not clear whether it is actually useful for convergence that a policy tries to influence the vintage choice of firms in a way that they acquire high vintages that they would not have selected without external pressure. Our analysis intends to shed light on this question by comparing non-directed with directed subsidy policies.[14] Finally, the financial burden of the subsidies of the cohesion policy is split among the two regions according to their real output per capita. This reflects how the EU is actually financed, i.e. contributions being earmarked to countries' gross domestic products.

The directed and the non-directed technology policy is studied for two labor market regimes. In one scenario we assume in both regions a relatively high wage replacement rate (70%) and also assume that the reservation wages of unemployed workers adjust at a speed we can empirically observe in Western European countries.[15] In the second scenario we analyze the effect of technology policies under the assumption that replacement rates in the low-tech region R2 are much lower (55%) and reservation wages adjust much faster there. The motivation for the consideration of this second treatment is that empirically replacement rates in many of the new EU member states from Eastern Europe are much

[14]Unfortunately, there is no empirical basis to quantitatively estimate the actual fraction of firms who receive subsidies although they do not invest on the frontier. The range of values of the parameter α which we consider in the policy analysis is driven by the observation that the qualitative implications of the directed policy do not change as we go beyond $\alpha = 0.3$, although they become more pronounced. Also, we believe that it is very challenging to implement a policy which is able to confine the payout completely to those firms that invest on the actual frontier.

[15]We use the findings in Burda and Mertens (2001) on wage losses of 17% after spells of unemployment in Germany assuming an average duration of 30 weeks.

lower than in Western European countries and labor markets tend to be more flexible.[16] The faster adjusting reservation wages may reflect the consequences of various labor market policies of the more recent past that aim at integrating unemployed workers more quickly into the labor market. Examples of such policies are the reduction of the duration of unemployment benefit payments to workers, tighter controls of unemployed workers' search intensity through employment agencies, or the introduction of the obligation to accept job offers that are below a worker's skills.[17]

For each of the considered policies 20 runs are conducted in both labor market scenarios, with each run encompassing 1400 months of which we show the last 1000 months skipping effects of initialization. For each policy the time series are pooled across labor market scenarios 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 a policy are evaluated by estimating the equation

$$\begin{aligned} Y_{t,p,i} &= s(t) + I_{[p(LM)=1]} s_{Flex}(t) + I_{[p(Tech)=1]} s_{Tech}(t) \\ &\quad + I_{[p(LM)=p(Tech)=1]} s_{Int}(t) + \eta_i^0 + \eta_i^1 \; t + \varepsilon_{t,p,i}, \end{aligned} \tag{9}$$

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 spline estimates will also be plotted in the figures in order to illustrate significance of the different policy effects over time. The effect over time of the policy in the scenario with an inflexible labor market in region R2 is given by $s_{Tech}(t)$. The difference in the policy effect between the two labor market scenarios is captured in $s_{Int}(t)$, which implies that the policy effect under a flexible labor market can be seen by considering $s_{Tech}(t)+s_{Int}(t)$. Finally, $s_{Flex}(t)$ gives an estimate of the effect of increased labor market flexibility on the considered variable in the base scenario without policy. [18]

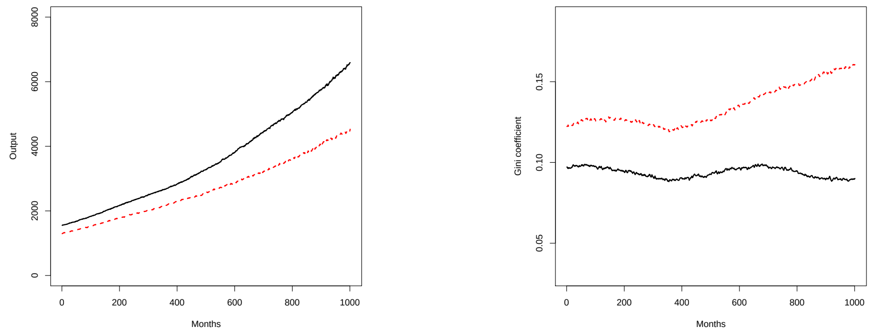
5.2 The Baseline Scenario

We proceed by showing that our agent-based macroeconomic model is able to replicate the stylized developments in terms of per capita income between regions and income

[16] Whereas the average net replacement rates for one earner families with two children slightly increased from the beginning of the seventies starting at about 65% for two percentage points for the old EU member states, the average for the new members states of the EU declined from above 60% to about 55%, recently, see van Vliet and Caminada (2012).

[17] In its 2007 Employment Outlook (OECD, 2007) the OECD surveys the various measures that have been taken by countries to activate the unemployed concluding that efforts to speed up re-employment are on a rise.

[18] All 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 mis-specified 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.



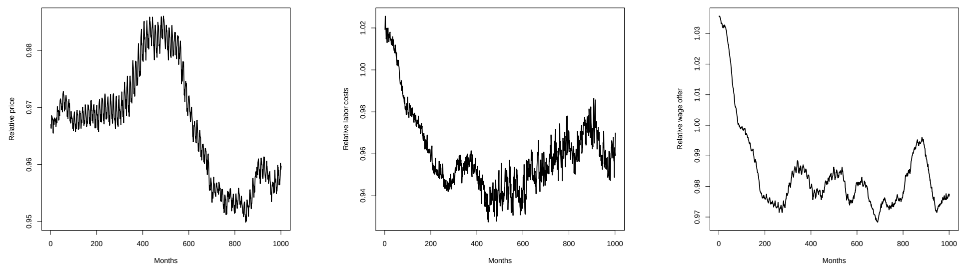
(a) (b)

Figure 2: Dynamics of output (a) and Gini coefficient (b) in both regions. Color code: black refers to the high-tech region R1 and red (dashed) to the low-tech region R2.

inequality within regions as outlined in Section 3. Once the behavior of the baseline model is explained we will go into the policy analysis applying the technology policies to our model, and augmenting it with an analysis of the technology effects under different schemes of reservation wage flexibility.

Figure 2 shows output per capita in the left panel and Gini coefficients – our measure for income inequality – in the right panel for the advanced (black line) and lagging regions (red line) in the baseline scenario where labor markets in R2 are inflexible. The lagging region 2 never accomplishes to close the gap in terms of per capita income to region 1. After about 80 years income in region 1 is five times higher where income in region 2 has only tripled. This process of income divergence between regions is accompanied by a positive trend of income inequality in the low-tech region 2. Over the whole time span the distributions of incomes within regions feature higher inequality in the low income region compared to the high income region. All these patterns are in accordance with the empirical evidence as presented in Figure 3, where we interpret region 2 as a representative of the group of southern European countries with relatively inflexible labor markets. To put the observation that the divergence between the different types of regions in Figure 2 is more pronounced than in Figure 3 into perspective, it should be noted that Figure 2 shows a much longer time horizon and is carried out under the assumption that no policies are present, which aim to prevent such diverging dynamics. We get back to this issue when discussing the effects of the different policies in our model framework.

What stands behind these developments can be explained with the help of Figure 3. Key for understanding the non-convergence is the inability of firms in region 2 to become competitive with firms in region 1. Plotting goods prices of region 1 relative to those of region 2 highlights that firms in region 2 have to charge higher prices on average which feeds back on that region's overall demand as households will prefer to purchase the less expensive goods. Firms in region 2 charge higher prices and, in particular after period



(a) (b) (c)

Figure 3: relative prices R1 to R2 (a), relative unit labor costs R1 to R2 (b), relative base wage offer (c)

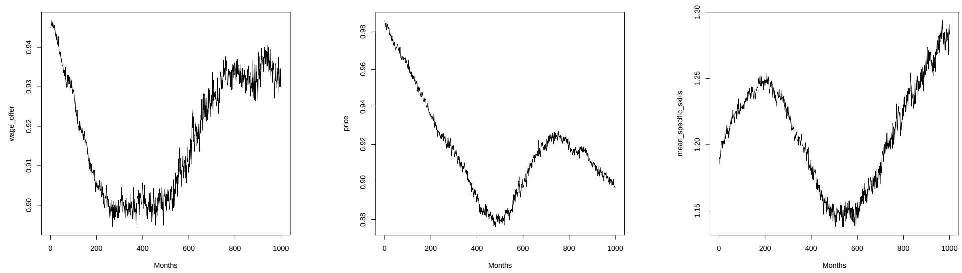
400, over time lose competitiveness relative to firms in region 1. This development is triggered by a decrease in the relative unit labor costs faced by firms in region 1 compared to that in region 2 (panel b).[19] This observation of decreasing relative unit labor costs finds its empirical counterpart in the strong convergence of unit labor costs that we showed in Figure 3 (c).

That firms in region 2 have on average higher unit labor costs than firms in region 1 is due to an intricate wage process taking place in region 2 and leading to higher average base wage offers in region 2 (panel c).[20] Region 2 is characterized by two groups of firms. On the one hand, we have firms that employ high quality capital close to the technological frontier. These firms have capital endowments very similar to the firms in the advanced region 1. They are able to pay relatively high wages in line with their workers' above average productivity. On the other hand, we have firms in region 2 which are technologically lagging behind but try to hire workers from the same (regional or country specific) labor market. The relatively high wages paid by technologically advanced firms in region 2 push up workers' reservation wages. Once a worker employed by one of these well performing firms loses her job, she will have a reservation wage reflecting her former wage paid. This implies for the lagging firms that they have to increase their base wage offers to successfully bid for workers. Consequently, their labor costs increase, and as they do not have high quality capital, higher labor costs cannot be covered by higher productivity. Also, in spite of the relatively high base wage offers the low-technology firms pay, they are not able to attract at a large scale workers with high general and specific skills. This in turn keeps their incentives to invest in advanced technologies low and the strong heterogeneity of firms in region 2 is preserved and actually grows over time.

Panels (a) to (c) of Figure 4 illustrate this mechanism by showing the ratios for several

[19]Initially firms in region 2 buffer the increase in relative unit labor costs by a reduction in their mark-up, such that the effect on relative prices occurs only with a certain delay.

[20]It should be pointed out that although base wage offers in region 2 are on average higher than in region 1, average wages in region 1 are substantially higher than in region 2 due to the difference in labor productivity between the two regions, see (6).



(a) (b) (c)

Figure 4: Relative base wage offers (high-tech/low-tech firms) in R2 (a), relative prices in R2 (b), relative level of specific skills in R2 (c)

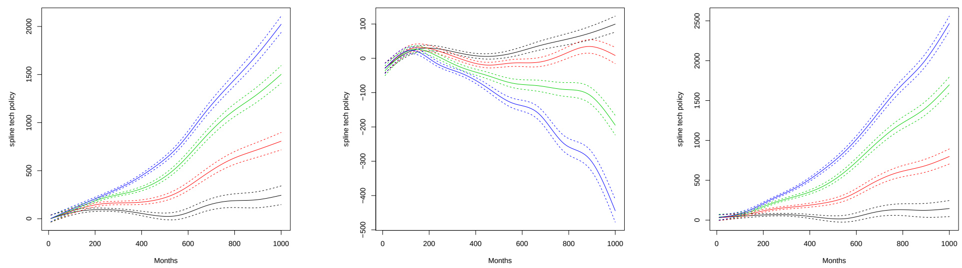
key variables for high- relative to low- tech firms. High-tech firms are defined as those firms operating with technologies above the median in region 2. Low-tech firms operate with technologies below the median. By taking the averages for the firms in those two groups, respectively, and dividing those one arrives at the aforementioned ratios. Panel (a) demonstrates that the low-tech firms indeed pay higher base wages and therefore charge higher prices (panel b). The persistent substantial difference in specific skills of workers at high-tech relative to low-tech firms in region 2 is demonstrated in panel (c). A similar picture would emerge if general rather than specific skills would be considered, but we abstain from showing this figure here.

5.3 Effects of Technology Policies

In this subsection we discuss the implications of the different technology policies for output and (inter- and intra-regional) inequality under inflexible labor markets in the target region. The case of flexible labor markets will be covered in the following subsection. We structure our analysis such that we state several main qualitative insights obtained from our simulation experiments as 'Results'. Then, for each of these results we provide the statistical analysis as well as a discussion of the economic mechanisms that are responsible for the observed finding.

Result 1: Under an inflexible labor market in the low-technology region all technology policies have a positive impact on total output in the economy. For a non-directed policy the effect is positive in the high and low-technology region. For sufficiently strongly directed policies the effect is positive in the low-technology region, but negative in the high-technology region.

The observations in Result 1 are evidenced in Figures 5 (a)-(c). The first panel shows the effect of the various technology policies on global output (adding up regions 1 and 2) for our default scenario, whereas the two other panels give the effects in each



(a) (b) (c)

Figure 5: Effect of the different technology policies on global output (a), output in region 1 (b) and output in region 2 (c) (color code: $\alpha = 0$: black, $\alpha = 0.1$: red, $\alpha = 0.2$: green, $\alpha = 0.3$: blue).

of the two regions. This figure, as well as most of the following figures in this section, relies on the penalized spline approach discussed above to show the dynamic effects of the different policies. Solid lines show the mean effect and dashed lines indicate one standard deviation bands. The global output effect is positive even for a non-directed policy but clearly trumped by all variants of directed policies. This is also the kind of policy effect we can observe for R2. However, for the high-tech region R1 the implications of the policy change do not only differ quantitatively but also qualitatively as we move from a non-directed to a (strongly) directed technology policy. Whereas for a non-directed policy the output effect is positive, the policy effect changes signs for more directed policies. Comparing the magnitudes of the policy effects with the output levels in the baseline scenario (see Figure 2 (a)) also suggests that the effects are quantitatively important.

In order to understand the economic mechanisms which underlie these policy effects we first focus on the non-directed policy. The primary effect of the policy is to reduce marginal investment costs of firms in region 2. Intuitively this should lead to a reduction of unit costs and prices of firms in region 2 relative to those in region 1, thereby improving the competitiveness of firms in region 2 and shifting demand towards firms from that region. Based on this reasoning it should be expected that the policy has positive effects only or at least primarily in region 2. In panel (a) of Figure 6 we depict the effect of the policy on the ratio on output produced in region 1 and region 2. It can be seen that the positive effect of the policy is indeed slightly larger in the target region and hence convergence is fostered. But the effect is very minor. The reason for this small effect is that the policy does not lead to a substantial increase in competitiveness of firms in region 2. Only initially the policy induces an increase of the ratio of prices charged by region 1 firms to that of region 2 firms. In the middle and long run, the policy reduces this relative price making firms in region 1 even more competitive (see Figure 6 (b)). In order to understand this effect the dynamics on the labor market have to be considered. As can be seen in panel (c) of Figure 6 the policy leads to a substantial increase of the base wage offers of firms in region 2 relative to that in region 1. Since the base wage determines

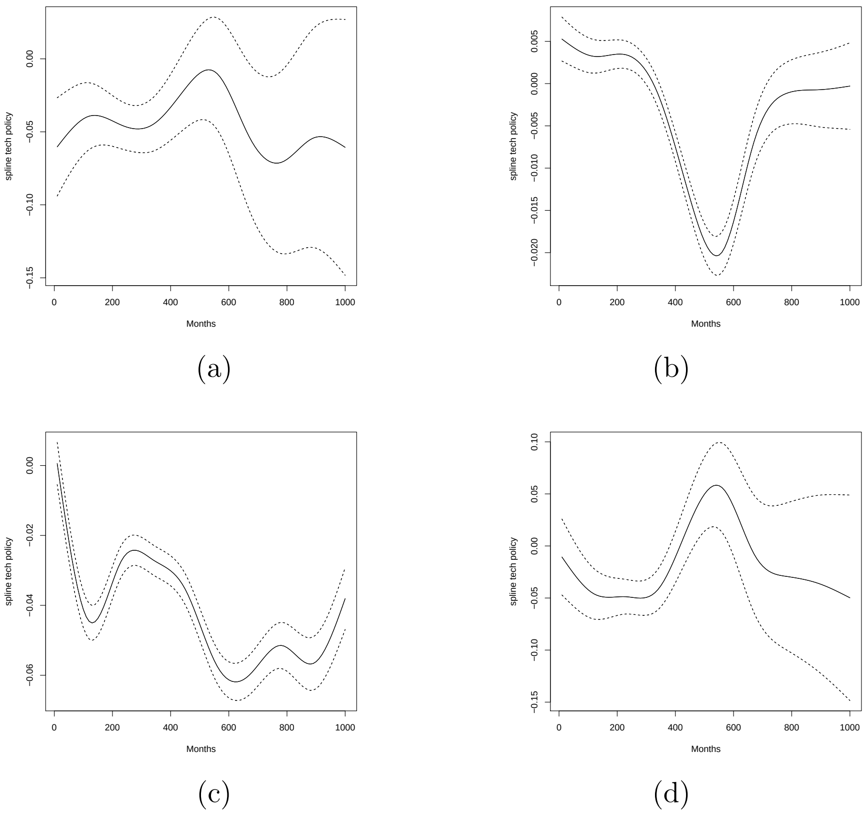


Figure 6: Effect of the non-directed technology policy on relative output (a), relative prices (b) relative base wage offer (c) and relative quality of capital stock (d).

the labor costs per productivity unit of a worker this increase contributes to an increase of unit costs in region 2 relative to region 1. Considering our findings with respect to the effects of the policy on relative prices we can conclude that this indirect wage effect of the introduction of the subsidy actually outweighs the direct effect of the policy on investment costs. As will become clear when we study the effects of the policy under a more flexible labor market in region 2, the strong heterogeneity of firms and workers in region 2 that emerges in the inflexible labor market setting (see our discussion of the baseline scenario above) is a crucial factor for this ambivalent policy effect. In particular, the low-tech firms in region 2 face problems to hire additional workers when they try to expand their production after the introduction of the non-directed subsidy which further drives up their base wage offers. Finally, in Figure 6 (d) the effect of the policy on the ratio of the average quality of capital stocks of firms in region 1 relative to region 2 is considered. Here, the policy has no significant positive effect on the technological convergence of region 2 firms toward those in region 1. The small positive effect with respect to output convergence is fully driven by the reduction of relative (investment) costs.

Having discussed the mechanisms underlying the effects of a non-directed technology policy we now consider how these effects change if the policy is able to induce a certain fraction of firms in region 2 to adopt the frontier technology. Figure 5 clearly shows that such directed policies indeed can foster convergence of the two regions in terms of real output. The output in the target region 2 is strongly positively affected whereas the output produced in region 1 is decreased due to the policy.

It should be kept in mind that in our model tax rates in the two regions are dynamically adjusted such that public expenditures are covered by taxes. Furthermore, the costs of the policy are fully covered by both regions. In this sense all policies are self-financed and the differences are not due to differences in the inflow of public funds (e.g. due to financing by the central bank).

The main reason for the positive convergence effects with respect to output of the directed technology policies is that, other than for the non-directed policies, a reduction of the technological gap between the two regions is achieved. Figure 7 (a) shows that under directed policies the ratio between the average quality of physical capital in region 1 to that in region 2 declines significantly, where the effect is stronger the more directed the policy is. Clearly, this effect is driven by the vintage choice of firms in region 2. The increased productivity of these firms, however, also has a positive second order effect for region 2 because it allows firms to expand production without hiring new workers. This reduces the pressure on the labor market, which was the main reason for the ambiguous effects of the non-directed policy. Panel (b) of Figure 7 shows that, at least for large values of α, the directed technology policies positively affect the ratio of base wage offers in the two regions. Considering the effect in each of the regions (not shown here) it becomes clear that this observation is driven by a reduction of base wage offers in region 2. For only weakly directed policies implications of the productivity increase on base wage offers is not sufficiently large to outweigh the negative forces described for the non-directed policy, and hence the overall effect on relative base wage offers is still slightly negative.

Together the positive effect of the directed policies on productivity in region 2 and the negative effects on labor costs leads to an increase in competitiveness of firms in region 2, which is expressed by an increase of the relative price of the good charged by firms in region 1 relative to those in region 2, and a simultaneous catching-up of firms in region 2 with respect to the mark-ups they can charge (see panels (c) and (d) in Figure 7). This explains the partial shift of demand, and therefore production, from region 1 firms to region 2 firms. The positive overall effect of the directed policies is also mainly driven by the reduction in unit costs of production in region 2. However, it should also be taken into account that in a closed model like ours the increased investment induced by the policies leads to an increase in income of households (since they own the investment good producer) and thereby strengthens demand.

Having discussed in detail the effects of a non-directed (i.e. $\alpha = 0$) or strongly directed ($\alpha = 0.3$) policy, we would like to point out that our model also suggests that a policy which is able to influence the technology choice only for a relatively small fraction of firms in the low-technology region 2 (i.e. $\alpha = 0.1$) is able to foster growth in that

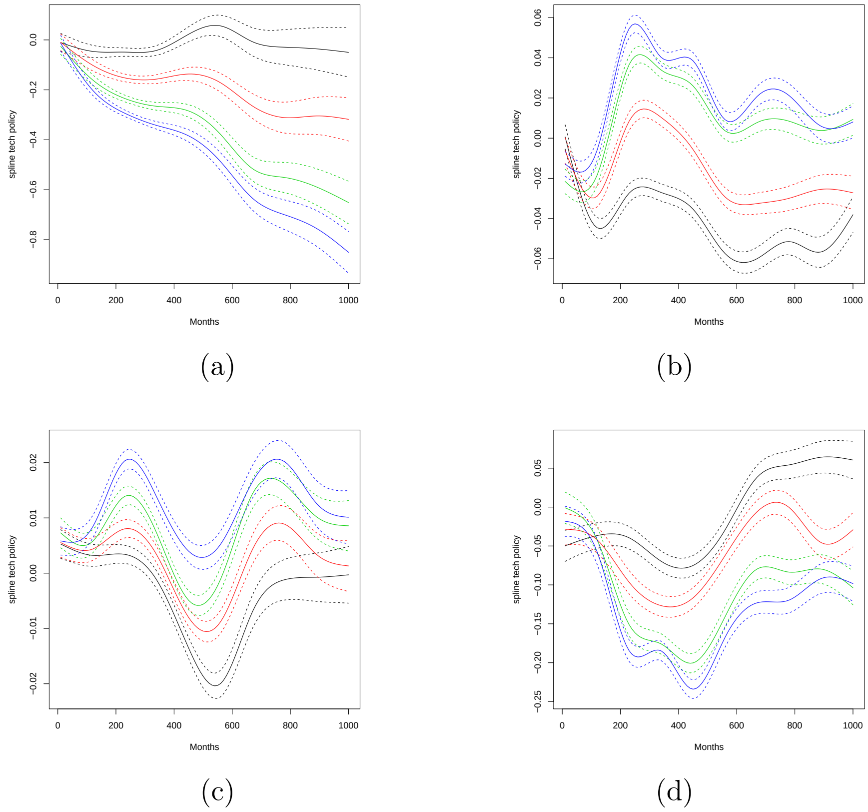
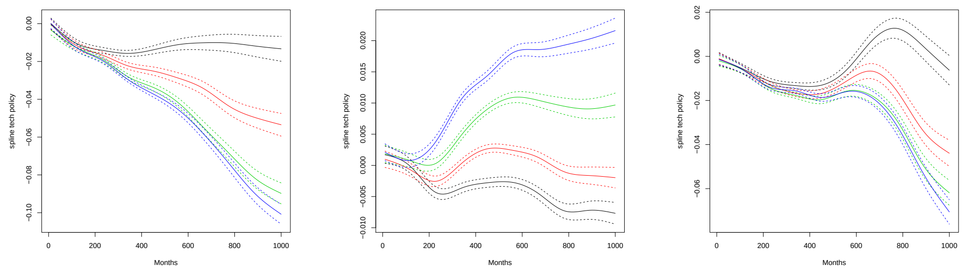


Figure 7: Effect of the different technology policies on relative quality of technology in the two regions (a), relative base wage offers (b), relative prices (c), and relative mark-ups (d). (color code: $\alpha = 0$: black, $\alpha = 0.1$: red, $\alpha = 0.2$: green, $\alpha = 0.3$: blue)

region without having any negative implications for the output produced in region R1 (see Figures 5(b)). This feature of the policy might be important since it should reduce potential objections that policy makers in region 1 might have against the implementation of policies that are potentially harmful to the growth dynamics in their region.

We now turn to the effect of the technology policies on overall inequality and the intra-regional distribution of income. As before we rely on the Gini coefficient of current income of households in order to measure income inequality. Using this indicator we obtain the following qualitative insight.

Result 2: All technology policies reduce the overall income inequality in the economy. For a non-directed policy inequality is persistently reduced only in the high-technology region. A sufficiently strongly directed policy reduces inequality in the low-technology region but makes the income distribution less equal in the high-technology region.



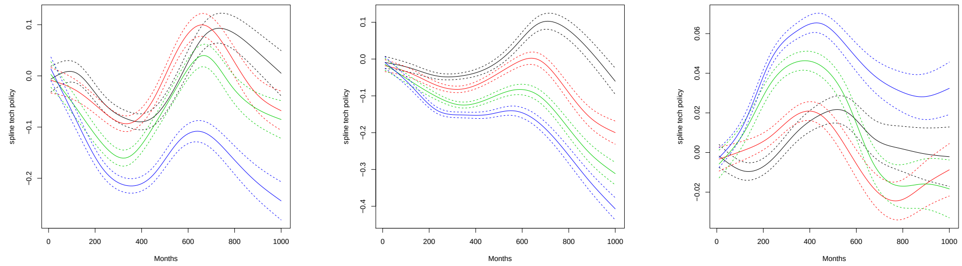
(a) (b) (c)

Figure 8: Effect of the different technology policies on the Gini coefficient of income in the whole economy (a), in region 1 (b) and in region 2 (c) (color code: $\alpha = 0$: black , $\alpha = 0.1$: red, $\alpha = 0.2$: green, $\alpha = 0.3$: blue).

Panel (a) of Figure 8 shows the overall effect of the different policies on income inequality in the whole economy. All policies decrease inequality in the default scenario. A more equal overall economy emerges with the technology policy for basically two reasons. First, the convergence process between the two regions brings the average income levels of workers in region 2 closer to the average income of workers in region 1. Secondly, the technology policy has a within region effect on income distribution. As is shown in panels (b) and (c) of Figure 8 the effect of the policies on the inequality within a region differs qualitatively between region 1 and the target region 2. Again, compared with the Gini coefficients of the income distributions of the baseline scenario (see Figure 2 (b)), the policy effects are also quantitatively sizable.

In region 2 the directed policies bring more firms to the technological frontier resulting in a reduction in heterogeneity between firms and more equal wages for workers. To some extent the segregated labor market driven by the firms' productivity distribution is overcome. This can be illustrated by considering the effect of the policies on the ratio of wage offers, specific skills and output between the groups of firms with productivity above and below the median. As can be seen in Figure 9 the directed policies reduce the ratio of the quality of physical capital between the two groups (see panel a), which then allows more firms in the lower productivity group to hire workers with an employment history at high-tech firms. This leads to a reduction of heterogeneity with respect to specific skills between firms (panel b) and reduces the strength of the phenomenon that low-tech firms have to make higher base wage offers in order to be able to hire (panel c). Clearly, the effects of the policies on base wage offers and specific skills increases the incentives of firms in the lower part of the productivity distribution to invest in high vintages, which reinforces the direct effect of the directed subsidies on vintage choice. For the non-directed policy none of these effects emerge since, as discussed above, this policy has no positive implications for technology choice, that would trigger such second order effects.[21]

[21]The policy effect described above is quite different from the mechanism highlighted in the literature

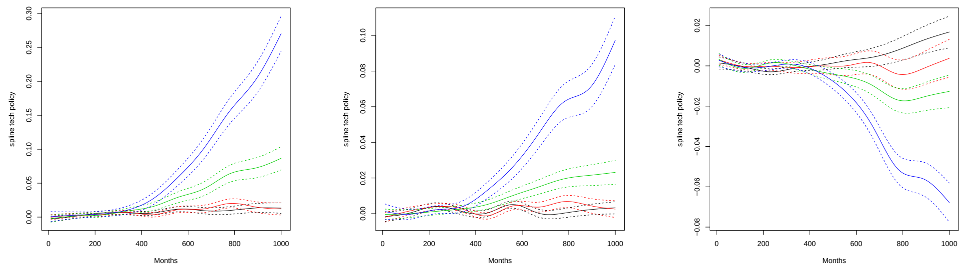


(a) (b) (c)

Figure 9: Effect of the different technology policies on ratios (high-tech/low-tech firms) in region 2: quality of capital stock (a), specific skills (b) and base wage offers (c) (color code: $\alpha = 0$: black , $\alpha = 0.1$: red, $\alpha = 0.2$: green, $\alpha = 0.3$: blue).

Considering region 1, the first observation is that all effects of the policies on inequality are much weaker than in the directed region 2 (compare the panels (b) and (c) of Figure 8). For the non-directed policy the induced change in the Gini coefficient is minor. For a weakly directed policy the effect is similarly small, but for $\alpha = 0.3$ a more pronounced effect arises. Here inequality in region 1 is increased and, as can be seen in Figure 10 the underlying mechanism is a 'mirror image' of what we observed in region 2. The heterogeneity of firms in region 1, both with respect to the quality of physical capital and with respect to specific skills, increases. Considering the dynamics of the distribution of these variables in the firm population in region 1 (not shown here) in the scenarios with and without policy it can clearly be shown that the upper part of this distribution is hardly affected by the policy, whereas the lower part becomes much more stretched out. Put differently, the group of firms staying very close to the frontier evolves in approximately the same way in both scenarios. However, under the directed policy the competition from firms in region 2 becomes stronger and this implies that some firms in region 1 that initially are only slightly weaker than the technological leaders invest at such a low rate that a considerable gap between their productivity and the frontier emerges. This is a self-reinforcing process implying that the firms at the frontier produce

on skill-biased technological change (e.g. Machin and Van Reenen, 1998) or on job polarization (e.g. Autor and Dorn, 2013) where the movement of firms to the technological frontier would worsen labor market perspectives of low skilled workers and therefore increase wage inequality. The reason for this difference is that, although our model exhibits complementarity between specific skills and the quality of physical capital, it does not include different types of tasks for workers. Differently from the polarization literature, where it is assumed that workers, who lack sufficient skills, cannot carry out certain tasks, which implies that such workers cannot profit from an increase in demand for such tasks associated with high skills, in our setting there is no distinction between different tasks and in principle, through on-the-job learning, all workers are able to acquire the specific skills needed for the frontier technology. Hence, in our setting also workers with low skills can potentially profit from the fact that in response to the directed technology policy firms upgrade their technologies and, due to the implied increase in competitiveness, increase their demand for workers. Hence, in our setting these policies can have positive implications also for the workers in the lower part of the skill distribution.



(a) (b) (c)

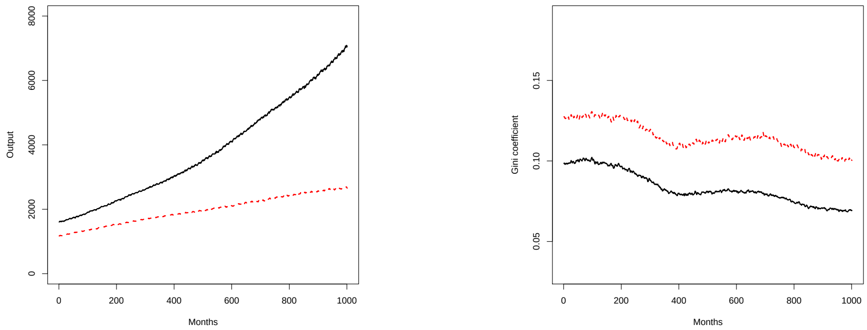
Figure 10: Effect of the different technology policies on ratios (high-tech/low-tech firms) in region 1: quality of capital stock (a), specific skills (b) and base wage offers (c). (color code: $\alpha = 0$: black , $\alpha = 0.1$: red, $\alpha = 0.2$: green, $\alpha = 0.3$: blue)

more output than in the scenario without the technology policy, which leads to a higher labor demand and higher relative base wage offers of the high-tech firms (see panel (c) of Figure 10). Overall, this positive effect of the technology policy on firm heterogeneity in region 1 explains the induced increase in income inequality in region 1.

5.4 The Role of Flexible Labor Markets

Our policy analysis in the previous subsection has been carried out under the assumption that the labor market in the low-tech target region 2 has similar institutional characteristics as the labor market in the high-tech region 1. Our results show that in such a setting the technology policy has to be directed. Only then it is able to induce a substantial fraction of firms in the target region to invest along the technological frontier in order to foster convergence with respect to output, and to reduce income inequality in the target region. As has been discussed in the Introduction many regions, at which cohesion policies of this type are targeted, are, however, characterized by relatively low wage replacement rates and strong incentives for workers to accept job-offers even if they pay less than previous employments. It is therefore an important question whether the qualitative findings of our previous discussion carry over to a setting with a more flexible labor market in region 2.

Before we study the effects of the different cohesion policies in the flexible labor market setting we should check, in how far the dynamics in the baseline scenario without policy changes if labor markets in region 2 are more flexible. Figure 11 shows the dynamics of regional output and Gini coefficients in the flexible labor market scenario. Comparing this figure to Figure 2 reveals that the divergence of output between the two regions is even more pronounced if labor markets in region 2 are flexible. On the other hand, the difference in Gini coefficients is much smaller in this scenario. Whereas inequality in the low-tech region is still larger compared to the high-tech region, the trajectories of Gini coefficients are much closer here compared to Figure 2 (b). Hence in terms of dynamics



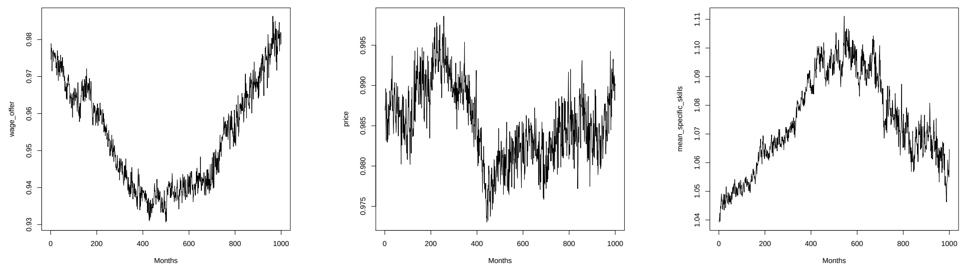
(a) (b)

Figure 11: Dynamics of output (a) and Gini coefficient (b) in both regions under a flexible labor market in R2. Color code: black refers to the high-tech region R1 and red (dashed) to the low-tech region R2.

of the Gini coefficient the low-tech region with flexible labor market lies between the low-tech region with inflexible labor and the high-tech region. This observation as well as the result that in terms of per capita output the low-tech region with a flexible labor market is below the low-tech region with inflexible labor market is consistent with the empirical evidence shown in Figure 3.

The reason for these changes in the dynamics is that with flexible labor markets the segregation of the workforce in region 2 into workers working only for high-tech firms and others mainly working for low tech-firms that we observed in the baseline scenario does not emerge. Due to the fast adjustment of reservation wages and lower replacement rates, workers who used to work for high-tech firms are willing to accept offers from low-tech firms. This implies for the low-tech firms in region 2 that they have higher chances to hire workers with high specific skills and that they are less frequently rationed on the labor market. Hence, the ratio of specific skills of workers between high- and low-tech firms is much smaller and the ratio of base wage offers between the two types of firms is much larger than in the baseline scenario (see Figure 12 (a) and (c) compared to Figure 4). As can be seen in panel (b) of this figure low-tech firms are now able to charge prices almost identical to that of high-tech firms. Therefore, high-tech firms face stronger competition both on the consumption goods and on the labor market. The wage costs of these firms are therefore higher and the investments smaller compared to the baseline scenario. The fact that a larger fraction of output in region 2 is produced by firms using capital of relatively low quality explains why the output in region 2 is smaller with flexible labor markets compared to the baseline scenario. Furthermore, these considerations imply that the heterogeneity of the firm productivity is smaller in this scenario, which explains that the trajectory of the regional Gini coefficient is below that in the scenario with inflexible labor markets.

This discussion shows that the existence of a flexible labor market in the low-tech



(a) (b) (c)

Figure 12: Relative base wage offers (high-tech/low-tech firms) in R2 (a), relative prices in R2 (b), relative level of specific skills in R2 (c) with a flexible labor market in R2.

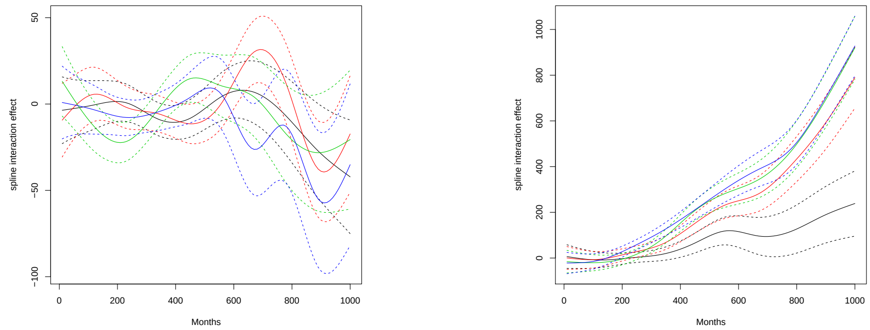
region is not necessarily conducive for output convergence towards the high-tech region. If we, however, consider the effects of the cohesion policies, it turns out that effects are more pronounced for regions with flexible labor markets.

Result 3: The effects of the technology policies on output in region 1 are (quantitatively) identical under an inflexible and flexible labor market in region 2. The effects on output in region 2 are substantially stronger under a flexible labor market.

Figure 13 illustrates how the effects of the policies differ between the scenarios of an inflexible and a flexible labor market in region 2. Formally, we show the penalized spline estimate of the interaction term $s_{Int}(t)$ from equation (9). Whereas, the interaction effect with respect to output in region 1 is essentially zero, for output in region 2 we obtain a significant and growing positive interaction effect for all considered policies. This means that the positive implications for the output dynamics in region 2 are much more pronounced if this region has a flexible labor market.

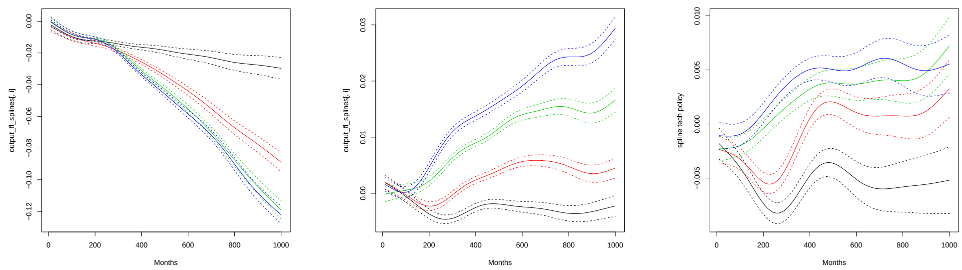
In order to understand the stronger effects of the policies in this scenario it should be remembered that in the scenario with inflexible labor markets the main inhibitor for the policy is an upwards pressure on base wages in region 2. This base wage increase is to a large extend due to the frictions on the labor market in region 2 that are implied by the combination of the strong firm heterogeneity and the reluctance of workers to accepts jobs that pay substantially less than the wage in their previous employment. As discussed above, under flexible labor markets the firm heterogeneity is strongly reduced and the frictions on the labor market are much smaller. Hence, the upward pressure of the technology policies on base wage offers in region 2 is strongly reduced and the policies have a much stronger positive impact on output (and also technology) in the target region.

With respect to intra-regional income inequality we observe that the effects of the policies under flexible labor markets differ significantly from the ones observed under inflexible labor markets.



(a) (b)

Figure 13: Difference between the two labor market scenarios of the policy effects on output in region 1 (a) and in region 2 (b). (color code: $\alpha = 0$: black , $\alpha = 0.1$: red, $\alpha = 0.2$: green, $\alpha = 0.3$: blue)



(a) (b) (c)

Figure 14: Effect of the different technology policies on the Gini coefficient of income in the whole economy (a), in region 1 (b) and in region 2 (c) in the flexible labor market scenario. (color code: $\alpha = 0$: black , $\alpha = 0.1$: red, $\alpha = 0.2$: green, $\alpha = 0.3$: blue).

Result 4: If the labor market in the low-technology region is flexible, the non-directed policy reduces intra-regional income inequality in both regions, whereas directed policies increase inequality in region 1 but have a negligible effect on inequality in region 2. Overall, inequality in the economy is reduced for all policies.

Result 4 is illustrated in Figure 14. In region 1 the effect on intra-regional inequality of the policies is qualitatively similar to the effects arising if the labor market in region 2 is inflexible (compare panels (b) of Figures 14 and 8). In the target region the effects are, however, quite different. First, it should be noted that the effects of the policies on the region 2 Gini coefficient are much smaller than in the inflexible labor market scenario. Second, in particular for the strongly directed policies the inequality reducing effect disappears. This is mainly due to the fact that under flexible labor markets the mobility of workers between high- and low-tech firms is much stronger and therefore there is no segregation of workers in groups working for high- and low-tech firms, respectively. In such a scenario, due to the directed policies more firms invest at the frontier. This implies that all workers profit in a similar way rather than that a large group of workers moves from the group of 'low-tech workers' to the group of 'high-tech workers' as it was observed in the inflexible labor market scenario. Therefore, the policy does not have a strong inequality reducing effect in region 2 under flexible labor markets. The overall income inequality in the economy is reduced due to the positive implication of the policy for convergence.

5.5 Robustness

In Appendix B we provide an extensive analysis of the robustness of our qualitative findings with respect to variations of key model parameters and aspects of the initialization. This analysis shows that the signs and the relative sizes of the policy effects, are robust across all the considered parameter constellations. Hence, our policy conclusions and the identified underlying mechanisms do not depend on the particular setup considered.

6 Conclusions

There are persistent and considerable gaps in income per capita across European countries. Moreover, countries with lower average per capita incomes are facing a more unequal distribution of incomes that has risen since the fall of the iron curtain. It is a major goal of European policymakers to foster convergence of incomes between and within regions. To this end sizable resources are spent on transfers to weakly performing regions under the umbrella of the ERDF. A prominently featuring policy is the subsidization of firms' investments.

We investigated the effectiveness of such a policy with respect to the convergence of regions and their income distributions under various scenarios which are characterizing the target regions' economic and institutional set-ups. The conjecture was that it is by no means clear to what extent a policy incentivizing firms to invest in better technologies can actually help achieving the policy goals when countries may be lacking the human capital to run this capital productively, do not have the public administration to survey the correct use of the transfer, and may have labor markets that function differently from those in the old member states. And indeed, our model based analysis leads to a quite distinct picture of the likely effects that we already summarized as *Results* in Section 5.3.

Deriving our results, it turned out to be important what kind of a distribution of firm productivities (which emerges endogenously in our model in the two regions) policymakers are facing. It could be shown that the effectiveness of a technology policy on the convergence of the two regions and its implication for the intra-regional income distribution is very much driven by the productivity distribution of firms in a region and the institutional set-up of the labor market. Fiercer competition for the scarce resource of skilled labor between firms and downward reservation wage rigidities may actually render technology policies less effective in terms of reducing inter- and intra-regional income inequalities. A main finding of our study is that technology policies have to be sufficiently directed, in the sense that they have to influence the technology choice of a sufficiently large fraction of firms, in order to have a substantial positive impact on the convergence between regions. In light of this finding the empirical evidence, that, in spite of the long-lasting application of ERDF instruments, in many target regions no catch-up to the high productivity regions could be achieved, suggests that the implemented measures might not be sufficiently successful in affecting firms' technology choices. Our results imply that increasing the directedness of ERDF measures could have a large positive impact on the effectiveness of cohesion policy.

To conclude, we would like to emphasize the potentially insightful approach of using an agent-based macroeconomic model for the evaluation of transfer policies. We believe that our simulation based approach to evaluating (EU) policies is a complementary tool to empirical studies. A model based analysis as ours makes it possible to look into the effectiveness of policies under different time-horizons. Very often empirical studies can only take a snapshot of the effects of the policy under investigation. When it comes to policies that explicitly target long-run goals such as economic convergence, evaluation tools should also be informative about the longer run effects. A macroeconomic analysis with a sound micro-foundation also gives us a tool at hand to analyze outcome variables which are of high policy relevance, for which real world data, however, very often does not exist or is of poor quality. Finally, and perhaps most importantly, the use of an agent-based macroeconomic model like ours allows for an investigation of the economic mechanisms underlying the policy outcomes. Rather than leaving the policymaker with a statement that the policy works or does not work without giving the reasons why this might be so, we can try to dismantle the underlying causal chains. In this contribution, we argued for the importance of firm behavior and productivity distributions of firms with regard to the unfolding of policy effects. It should be an interesting exercise to take this insight to the data and evaluate policies using firm level observations. An implication of our study to be tested could be in how far firms receiving cohesion funds have chosen different technologies than they would have otherwise, and how this affected productivity in the targeted regions compared to those that did not receive subsidies.

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Appendix

A Simulation Parameters

Table 3 and 4 give the default parameter setting used in the policy experiments discussed in the paper.

Table 3: Number of agents per region*

Households	800	800
Firms	40	40
Government	1	1
Banks	1	1

*There is one capital good producer serving both regions, and one central bank

Table 4: Values of selected parameters.

Parameter	Description	Value
u	Wage replacement rate*	0.70
Φ	Target wealth/income ratio	16.67
κ	Adjustment wealth/income ratio	0.01
δ	Capital depreciation rate	0.01
χ	Service level for the expected demand	0.8
γ^C	Intensity of consumer choice	9.0
ρ	Discount rate	0.02
S	Firm time horizon in months	24
Δq^{inv}	Technological progress	0.05
λ	Bargaining power of the capital goods producer	0.5
γ^v	Logit parameter for vintage choice	30.0
φ	Wage update	0.01
$\overline{v}$	Number of unfilled vacancies triggering wage update	2
ψ	Reservation wage update*	0.01
$\chi(b_h^{gen} = 1)$	Specific skills adaptation speed for low skilled workers	0.0125
$\chi(b_h^{gen} = 2)$	specific skills adaptation speed for high skilled workers	0.03703

*Notes: *Parameters changed in conjunction with the flexibility policy in Section 5.4. We chose a wage replacement rate of 70% which is in line with replacement rates documented by the OECD (see http://www.oecd.org/social/benefits-and-wages.htm). Data on wealth and income distributions can be found at http://www.oecdbetterlifeindex.org/topics/income/. This data suggests that on average net financial wealth is about three times larger than yearly disposable household income in OECD countries. However, these figures only loosely relate to the idea of the buffer stock saving model as cited data should also reflect savings decisions for retirement whereas the buffer stock theory is about liquidity constrained consumers facing risky income. As estimates of the buffer stock theory suggest that the marginal rate of consumption of an increase in permanent income is smaller but close to one, see, e.g. Carroll (2009) or Blundell et al. (2008), we chose a target wealth income ratio (Φ) and an adjustment parameter (κ) such that the marginal propensity to consume out of average income of the households is close to one. Capital depreciation rates are documented by in the Penn World Tables. Figures reported there are slightly lower than our monthly depreciation rate of 0.01%. However, one should keep in mind that our only capital good is machinery and no real estate is modeled. The intensity of the consumer choice stems from estimated multi-nominal logit models of brand selection. Estimates based on market data Krishnamruthi and Raj (1988) provide a lower bound of 6. The annual growth rate of the technological frontier of around 1.8% has been chosen in a way that the productivity growth rate in the high-tech region is close to 1.5%, which corresponds to typical values in Western European countries. The parameter on wage updates is set to match wage growth in Germany during the decade of full employment in the sixties, while the parameter value for the adjustment of the reservation wage is based on reported wage losses of approximately 17% after spells of unemployment in Germany (see Burda and Mertens, 2001), and an average duration of unemployment of 30 weeks. All other parameter where direct evidence was not available have been chosen to yield simulation data that is capable of reproducing a set of stylized facts, see Table 5.*

B Robustness Checks

Our discussion in Section 5 was based on simulations carried out with a specific setup of the model. The setup included the default parameter setting as described in Figure 4 as well as initial characteristics of the population. Regarding the latter, it should be clear from the discussion in Section 5 that the initial productivity distribution of firms and the skill endowment of households is of particular importance in the context of our policy experiment.

Hence, an important question that might arise concerns the robustness of our policy analysis with respect to deviations from this model setup. In order to answer this question, we have carried out substantial robustness checks to confirm that our qualitative findings stay intact also if we deviate from our default setup within a reasonable range. We discuss the robustness of the results with respect to changes of the most important model parameters. Furthermore, we check how a change of the initial productivity distribution and the human capital endowment affects the qualitative results of our policy analysis.

B.1 Parametrization

In what follows we show the robustness of our findings with respect to a variation of five specific parameters of the model, which have been identified to have a considerable impact on the simulation outcome. The five parameters are the price sensitivity of consumers, the speed of change of the technological frontier, the discount rate applied to the effective productivity of the investment good, the depreciation rate and the replacement rate for unemployment benefits.

For each of these parameters, we first demonstrate the sensitivity of the evolution of regional output and the Gini coefficient in region 1 and 2 without policy, for which Figure 2 can be considered as the counterpart in the main text. Then, for the policy scenario with an inflexible labor market in region 2, we illustrate how a variation of the respective parameter influences the policy effects on regional output and Gini (analogous to Figure 5 and 8). Finally, we check the robustness of the interaction of the tech policy with making the labor market in region 2 flexible (analogous to Figure 13 and 14). All time series are estimated by applying penalized spline methods; for the sake of clarity, we abstain from plotting confidence bands here. Furthermore, due to space constraints, we restrict our discussion on the non-directed tech policy ($\alpha = 0.0$) and the technology policy with the strongest directedness ($\alpha = 0.3$).

The first parameter with a strong impact on the simulations is the speed of technological change. As described in Section 4.2.4 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 0.03 and 0.06. The default value in the body of the paper was $\Delta q^{inv} = 0.05$.

Figure 15 shows how the variation of this parameter affects the evolution of regional output and the Gini coefficient in the baseline scenario. It can clearly be seen that the speed of technological change has a strong impact on the output trajectories as well as income inequality. Furthermore, the figure illustrates that varying this parameter also affects the policy effects quantitatively, where the policy effects seem to become the stronger the faster the frontier grows. However, the qualitative features worked out for the default parameter setting stay intact for the entire considered range of the parameter.

The second 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 determines the scope for price changes of individual firms and the overall competitiveness on the consumption goods market. In the body of the paper 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. Figure 16 illustrates the results of the robustness check. 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 (monthly) depreciation rate, which in the default setting was $\delta = 0.01$ 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 discount rate was varied between 0.01 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 17-19, respectively. 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 (see Table 1) are robust with respect to alternative parameter specifications.

B.2 Initial Skill and Productivity Distributions

In our policy experiments, we assumed that region 1 was technologically advanced at the outset of the simulation. More precisely, we assumed that the capital productivity of firms located in region 1 as well as the specific skills of workers populating the same region are with a level of 1.5 close to the initial frontier technology that exhibits a productivity of 1.7. At the same time, the labor force in region 1 was characterized by a general skill distribution featuring more high-skill than low-skill workers (80 to 20%). Region 2, in contrast, was assumed to be a low-tech region with a productivity level off the frontier, where we assumed a level of 1.0 for both, technical productivity and specific skills. Also

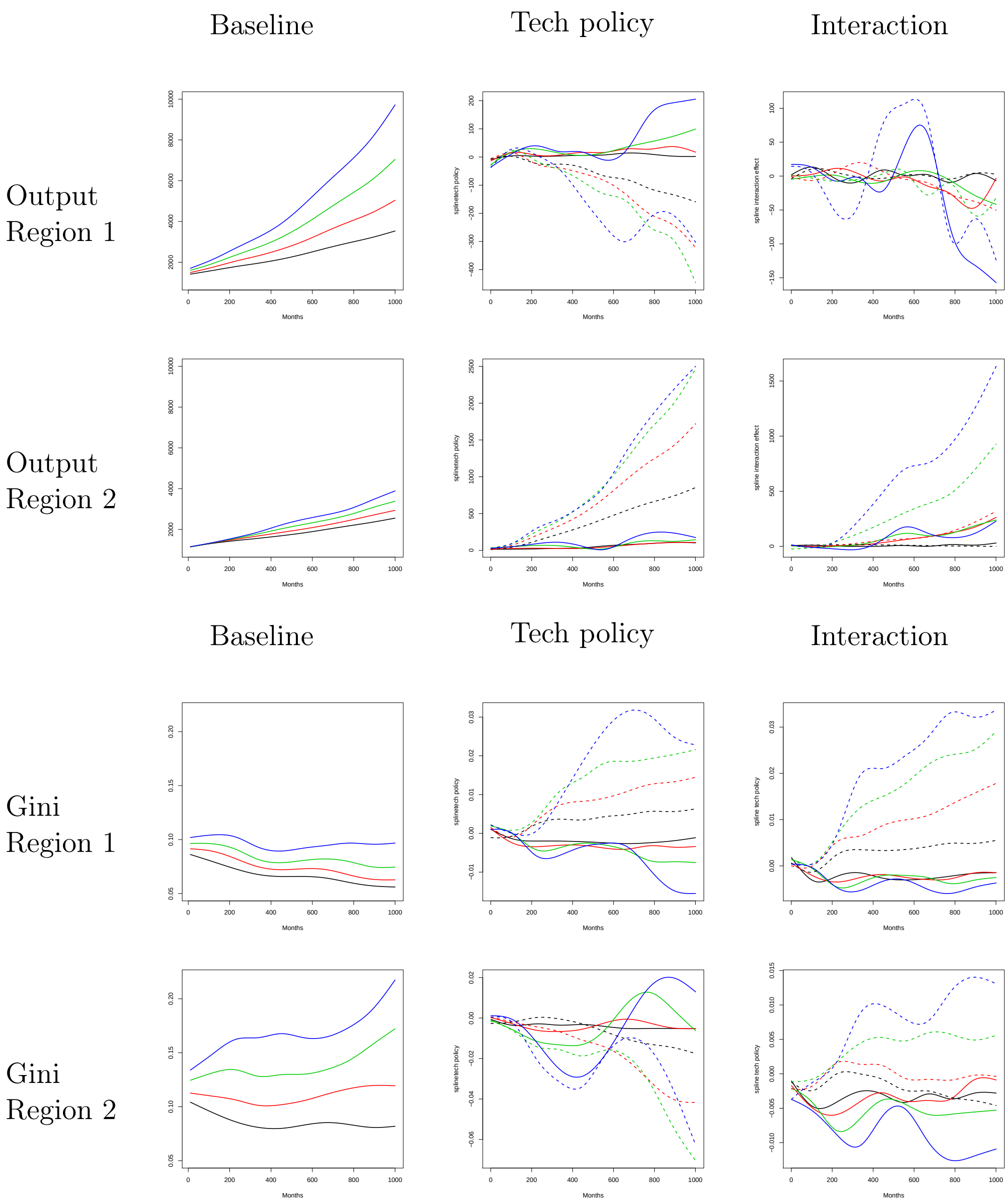

Figure 15: Effects of a variation of the speed of technological change on the dynamics of regional output and inequality in the baseline scenario as well as on the policy effects of an non-directed ($\alpha = 0.0$, solid lines) and directed policy ($\alpha = 0.03$, dashed lines). Color code: $\Delta q^{inv} = 0.03$: black, $\Delta q^{inv} = 0.04$: red, $\Delta q^{inv} = 0.05$: green, $\Delta q^{inv} = 0.06$: blue.

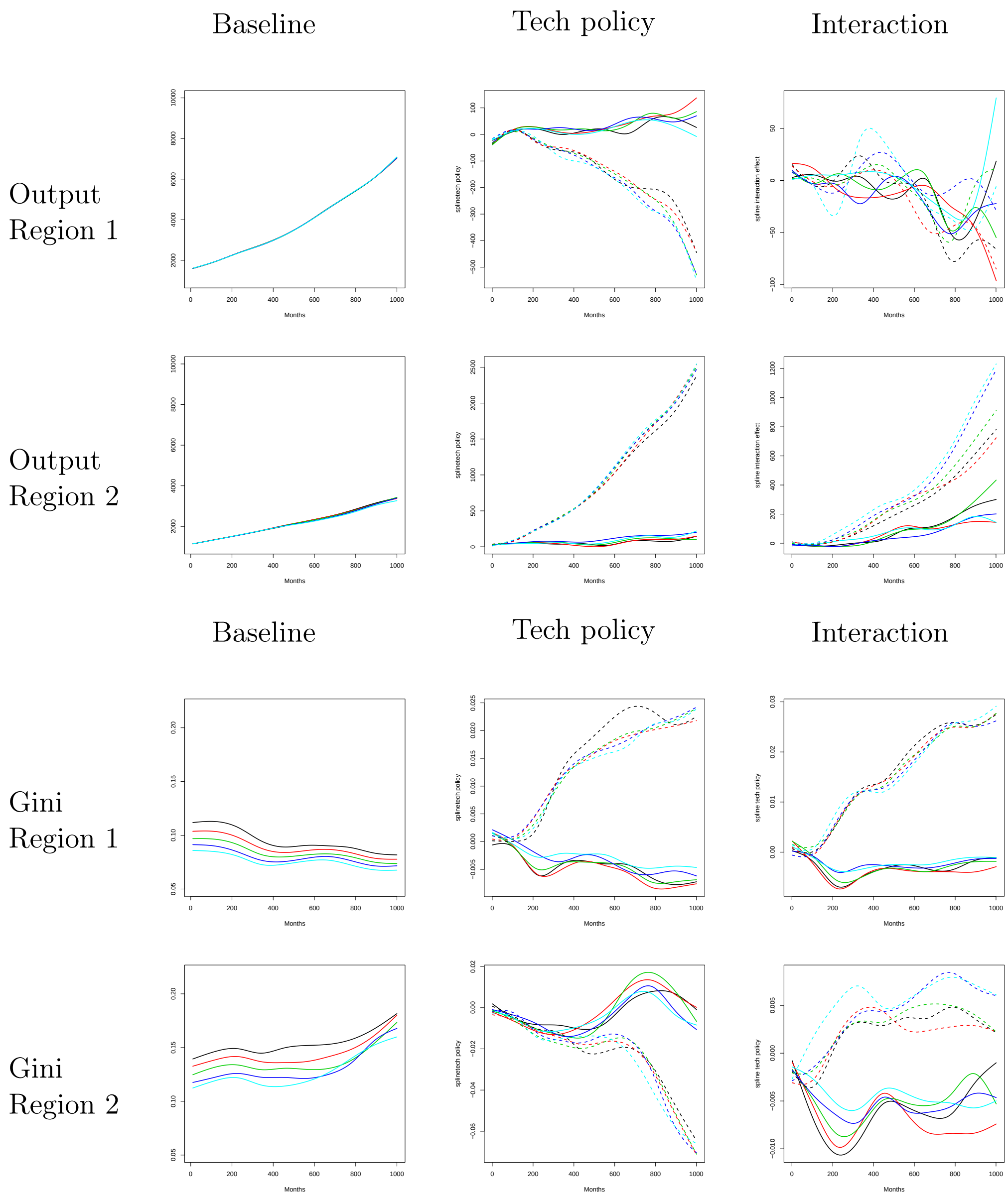

Figure 16: Effects of a variation of households' price sensitivity on the dynamics of regional output and inequality in the baseline scenario as well as on the policy effects of an non-directed ($\alpha = 0.0$, solid lines) and directed policy ($\alpha = 0.03$, dashed lines). Color code: $\gamma^C = 7.0$: black, $\gamma^C = 8.0$: red, $\gamma^C = 9.0$: green, $\gamma^C = 10.0$: blue, $\gamma^C = 11.0$: light blue.

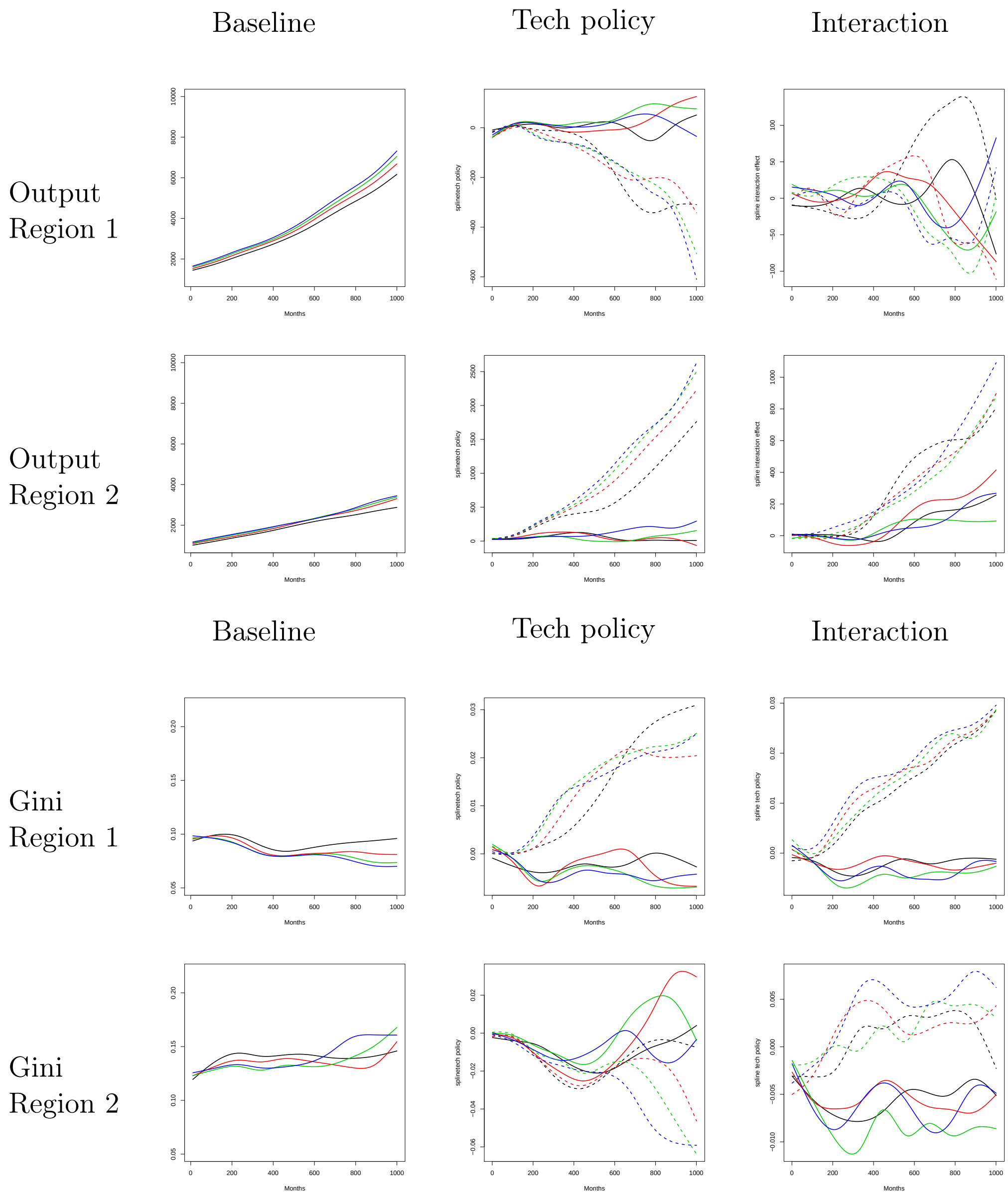

Figure 17: Effects of a variation of the depreciation rate on the dynamics of regional output and inequality in the baseline scenario as well as on the policy effects of an non-directed ($\alpha = 0.0$, solid lines) and directed policy ($\alpha = 0.03$, dashed lines). Color code: $\delta = 0.006$: black, $\delta = 0.008$: red, $\delta = 0.01$: green, $\delta = 0.012$: blue.

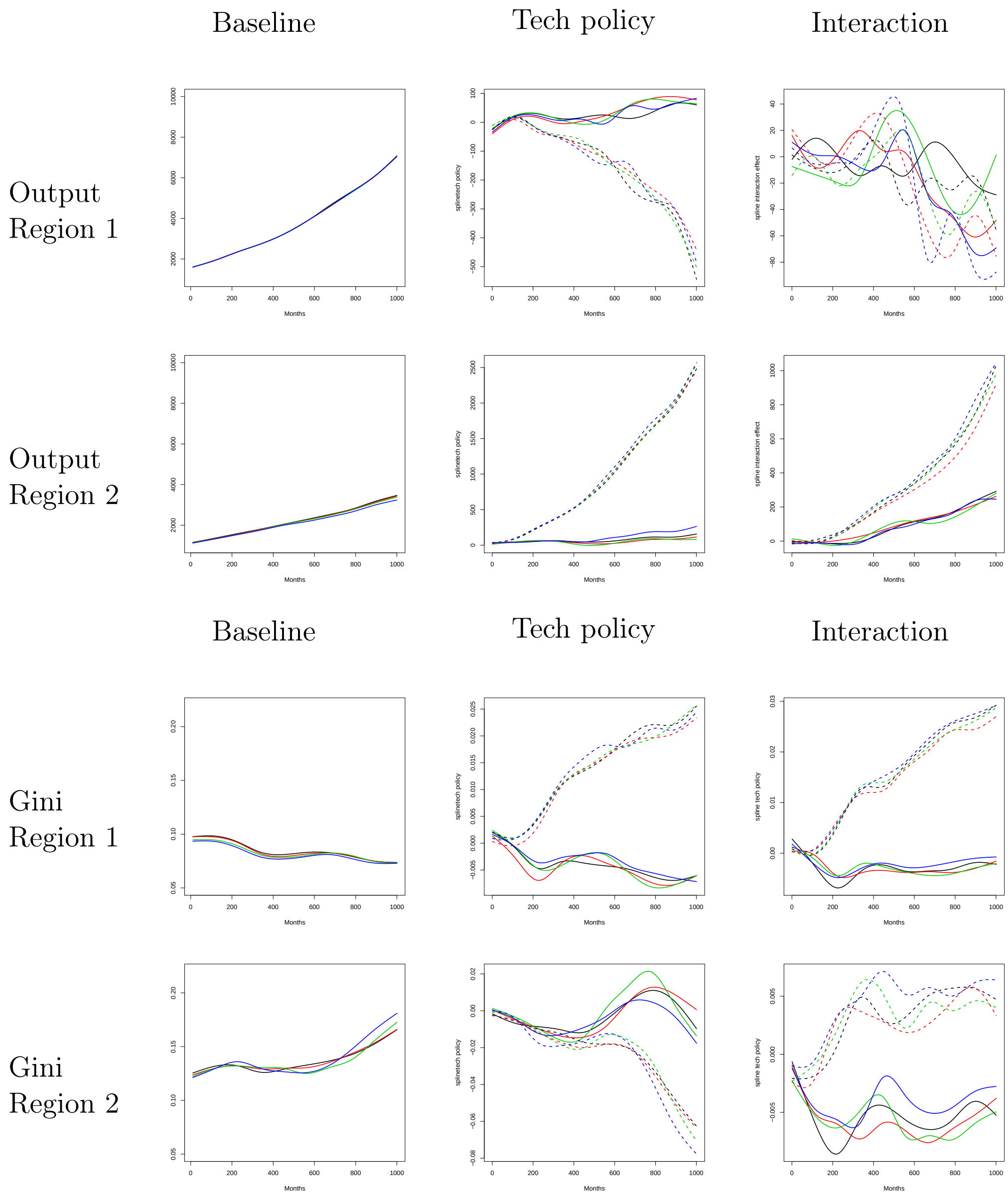

Figure 18: Effects of a variation of the discount rate on the dynamics of regional output and inequality in the baseline scenario as well as on the policy effects of an non-directed ($\alpha = 0.0$, solid lines) and directed policy ($\alpha = 0.03$, dashed lines). Color code: $\delta = 0.01$: black, $\delta = 0.02$: red, $\delta = 0.03$: green, $\delta = 0.04$: blue.

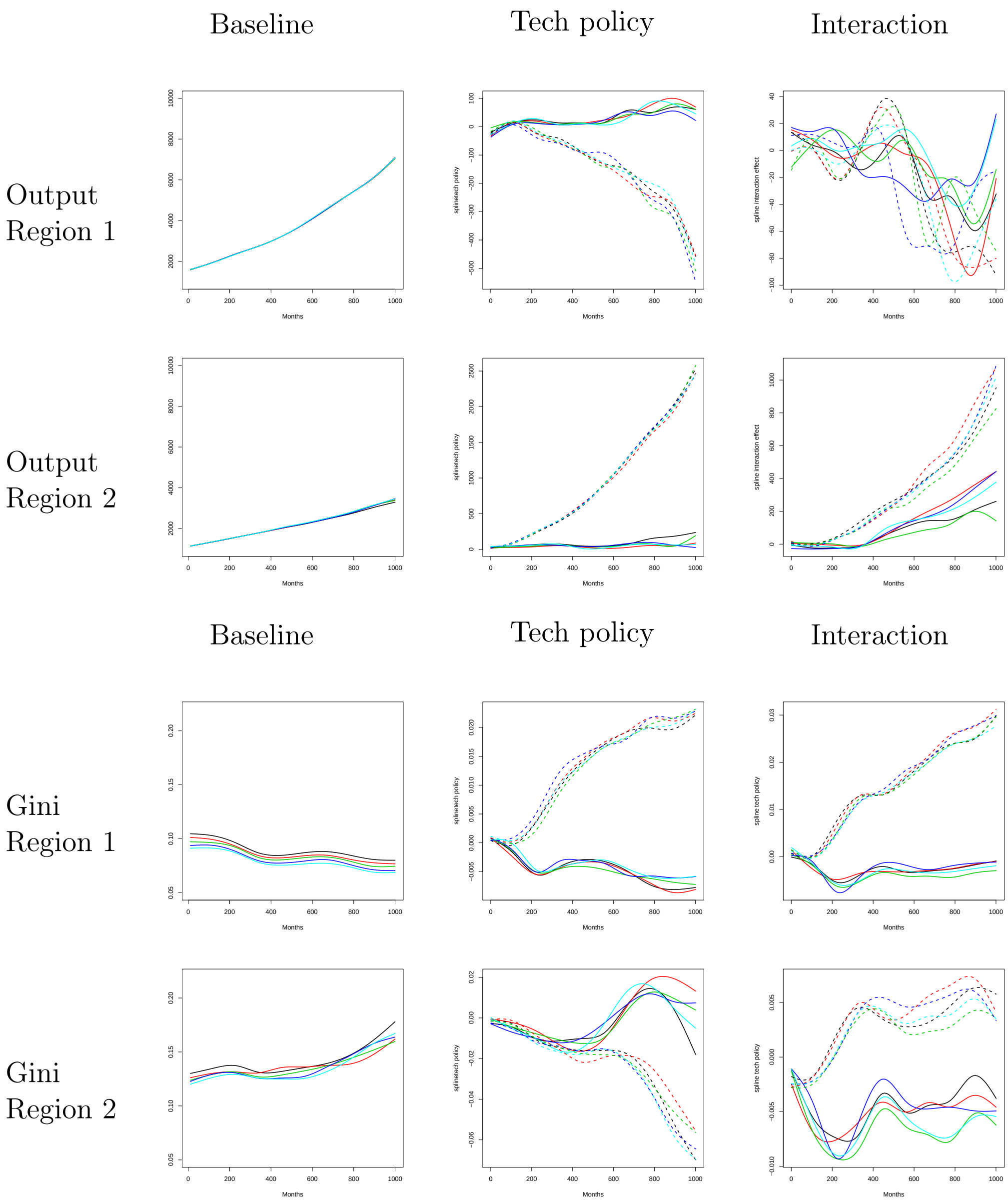

Figure 19: Effects of a variation of the unemployment insurance replacement rate on the dynamics of regional output and inequality in the baseline scenario as well as on the policy effects of an non-directed ($\alpha = 0.0$, solid lines) and directed policy ($\alpha = 0.03$, dashed lines). Color code: $\delta = 0.6$: black, $\delta = 0.65$: red, $\delta = 0.07$: green, $\delta = 0.75$: blue, $\delta = 0.8$: light blue.

the general skill distribution was assumed to be inferior. The distribution of high-skill workers to low-skill workers was 20 to 80%.

In the following, we demonstrate how the results of our policy experiment change if we lower the initial gaps between region 1 and 2. Figure 20 depicts the effect of lowering the initial productivity gap between region 1 and 2 by increasing the productivity level in region 2 from 0.9 to 1.2 while keeping the initial productivity level in region 1 constantly close to the frontier. The figure illustrates that qualitatively the policy effects are not affected.

Figure 21 shows the effect of equalizing the general skill differentials between the regions. Here we varied the (static) general skill distribution from the default combination of 80% high-skill workers and 20% low-skill workers in region 1, and 20 to 80% in region 2 stepwise to an almost equal distribution of 60 to 40% high- and low-skill workers in region 1 and the opposite in region 2. The figure illustrates that the effects of the tech policy under inflexible labor market stay intact. For the interaction effects between the tech policy and labor market flexibility, one can see that a negative interaction effect on output in region 2 disappears as skill distributions become almost equal. Hence, the combination of both policies reduces inequality in region 2. This is what one would have expected given the mechanisms at work. A relatively larger supply of high skilled workers in region 2 is at least partially a substitute to a more flexible labor market as it also allows expanding firms to draw on a skilled labor force.

C Stylized Facts replicated by the Model

It has been demonstrated in, e.g., Dawid et al. (2012b) and Harting (2014) that the Eurace@Unibi model is able to reproduce a considerable number of stylized facts on both, the macro and micro level. However, the studies in which the model's ability to reproduce stylized facts have been documented used one-region setups of the Eurace@Unibi model.

The aim of this appendix is to demonstrate that also the two-region version of the model together with the specific setup and parametrization used for the present study is able to replicate various stylized facts. In Table 5 we provide an overview of the reproduced stylized facts in four broad categories (business cycles, labor and credit markets, firm distributions). Additionally, we provide (exemplary) references to the literature where the stylized facts have originally been documented. The list of stylized facts in Table 5 is based on simulations carried out with the baseline setting of the model encompassing 500 months. The specific properties of the simulations that match stylized facts are illustrated in Table 6 and 7 and in Figures 22 to 25. In particular, we illustrate:

- The average annual growth rate of the time series total output as well as its volatility measured by the percentage standard deviation of the cyclical component is listed in Table 6. The table shows the means and, in parentheses, the standard deviations of 10 batch runs. The time series total output have been detrended by applying a bandpass filter.

- The relationship between the aggregate business cycle and various macroeconomic

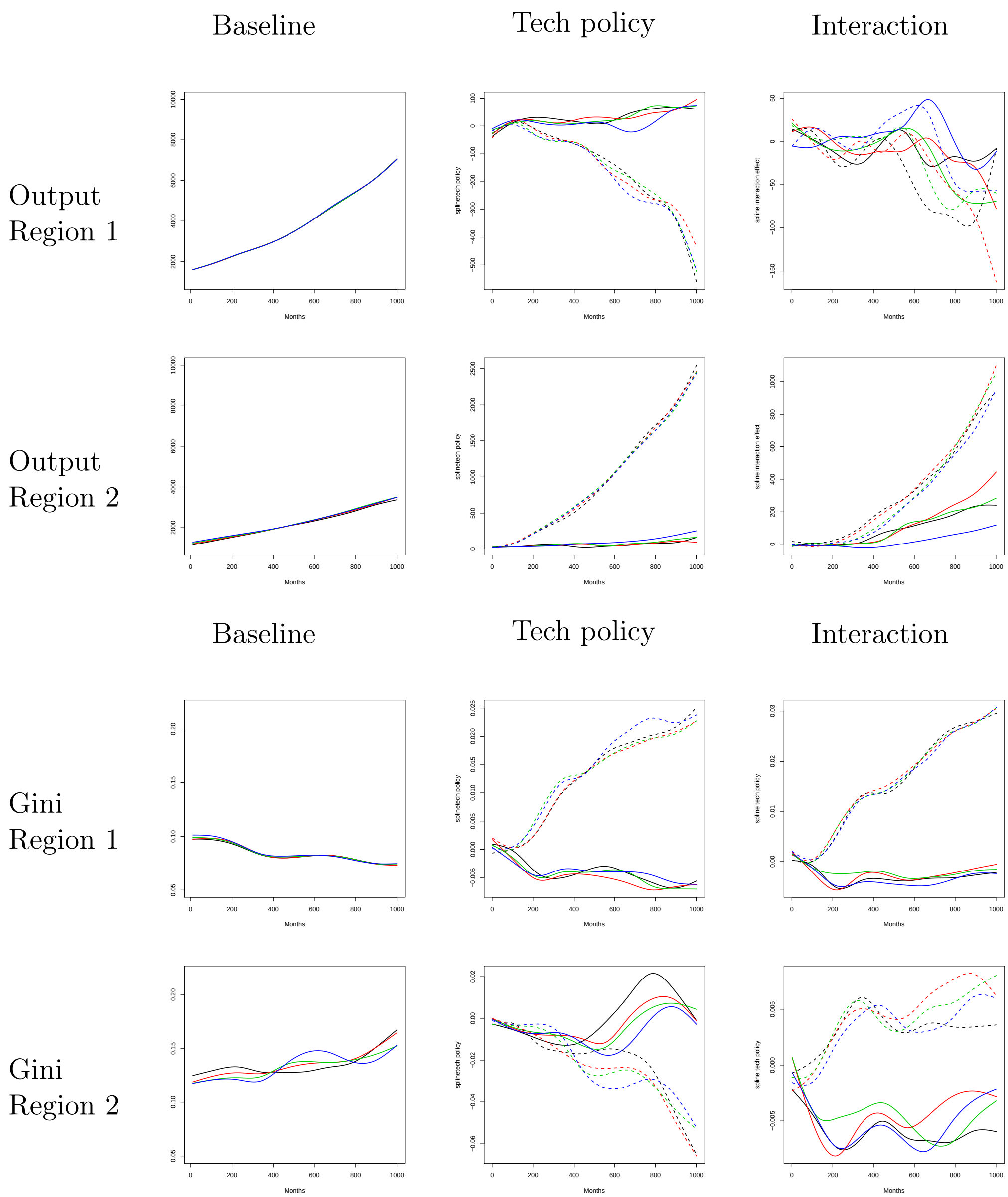

Figure 20: Effects of a variation of the initial productivity levels in region 2 on the dynamics of regional output and inequality in the baseline scenario as well as on the policy effects of an non-directed ($\alpha = 0.0$, solid lines) and directed policy ($\alpha = 0.3$, dashed lines). Color code: initial productivity in region 2 0.9 : black, initial productivity in region 2 1.0: red, initial productivity in region 2 1.1: green, initial productivity in region 2 1.2: blue.

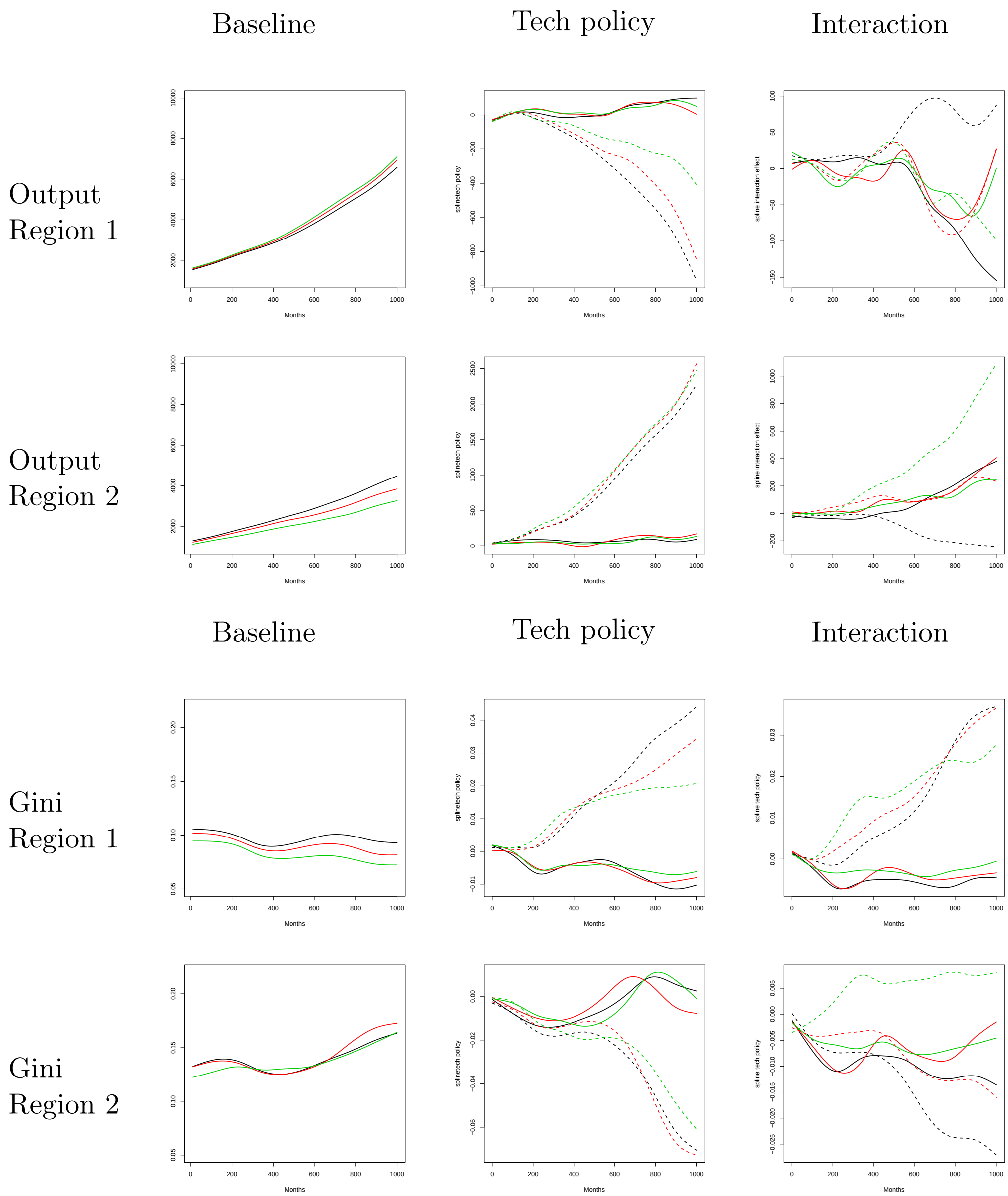

Figure 21: Effects of a variation of the general skill distributions in region 1 and 2 on the dynamics of regional output and inequality in the baseline scenario as well as on the policy effects of an non-directed ($\alpha = 0.0$, solid lines) and directed policy ($\alpha = 0.03$, dashed lines). Color code: high/low 60:40% in region 1 and 40:60% in region 2: black, 70:30% and 30:70%: red, 80:20% and 20:80%: green.

variables, such as prices, productivity, employment, investment, and consumption are documented in Table 7. This is done by examining the strength of the cross-correlation between the aggregate cycle and the cyclical components of individual time series by means of bandpass filters. The auto-correlation of total output can be used to assess the persistence of the cycle, whereas the cross-correlations indicate the co-movement of the macroeconomic aggregates. Again, the values shown in the table are the means and standard deviations of 10 batch runs.

- Figure 22 plots the bandpass filtered time series of total output together with consumption and investments (panel a) as well as with unemployment and vacancies (panel b) for a single run. This is supposed to show the lag structure between these time series as well as the relative magnitude of their amplitudes.

- Important labor market characteristics are summarized in Figure 23, which plots the Beveridge curve for the relationship between unemployment rates and vacancy rates as well as the Phillips curve for the link between unemployment and inflation. These plots are based on a single run.

- Figure 24 shows distributional aspects of firms based on a single run. Panel (a) illustrates the firm size distribution by plotting the instantaneous distribution of firms' output at an advanced point in time of a single run. Panel (b) shows a histogram of the distribution of annual growth rates of firms' capital stocks of the same run in order to illustrate the size distribution of firms' investments.

- Figure 25 illustrates properties of the productivity distribution of firms. In panel (a) and (b) we depict the average productivity of high-tech and low-tech firms in Region 1 and 2 thereby relying on the same grouping criterion as in Section 5.2, i.e. high-tech firms are defined as those firms operating with technologies above the local median. In the lower panels of this figure, we fix the groups of high- and low-tech firms at the beginning of the considered time horizon and follow the evolution of the average productivity in the two groups over time. This is supposed to illustrate a certain level of persistence in terms of productivity gaps among firms.

Table 5: List of stylized facts matched by the Eurace@Unibi model.

Stylized Facts	Source	Reference for stylized fact in this paper
Business cycle properties:		
Growth rates, business cycle volatility and persistence	Sorensen and Whitta-Jacobsen (2005), Stock and Watson (1999)	Table 6, Table 7
Co-movement of key variables with the business cycle: 1. Pro-cyclical: consumption, investments, employment, vacancies 2. Counter-cyclical: wages, mark-ups, unemployment	Stock and Watson (1999)	Table 7
Magnitude of volatility of investments, vacancies, employment and consumption compared to volatility of output	Stock and Watson (1999)	Figure 22
Labor market properties:		
Beveridge curve, Phillips curve	Blanchard et al. (1989)	Figure 23
Firm size and productivity distributions:		
Right-skewed firm size distribution	Dosi et al. (2006)	Figure 24 (a)
Productivity heterogeneity among firms	Dosi et al. (2006)	Figure 25
Persistence of productivity gaps between firms	Dosi et al. (2006)	Figure 25 (c) and (d)

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series Table 5 – continued from previous page

Stylized Facts	Source	Reference for stylized fact in this paper
Lumpiness of investments	Doms and Dunne (1998), Dosi et al. (2006)	Figure 24 (b)
Credit market properties:		
Financial leverage increases during the boom phase and decreases during the contractionary phase of the business cycle	Jordà et al. (2013)	Table 7

Table 6: Annual growth rate and business cycle volatility, measured as percentage standard deviation of the bandpass filtered time series of total output. Standard deviations in parentheses.

	Mean growth rate (in %)	Standard deviation (in %)
Output	0.01847	0.00822
	(0.00034)	(0.00140)

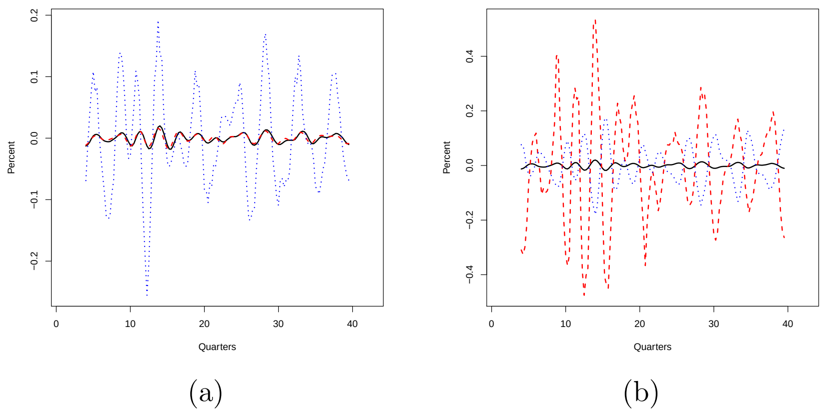


Figure 22: Band-passed filtered time series for output (black solid line), consumption (red dashed line), and investment (blue dotted line) (panel a); band-passed filtered time series for output (black solid line), vacancies (red dashed line) and unemployment (blue dotted line) (panel b).

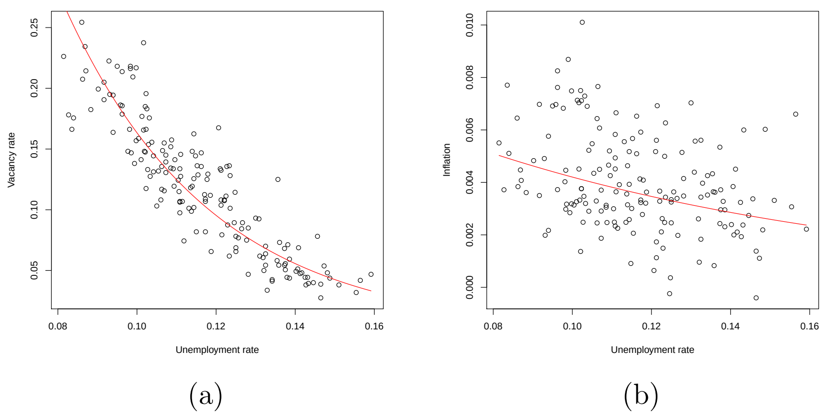
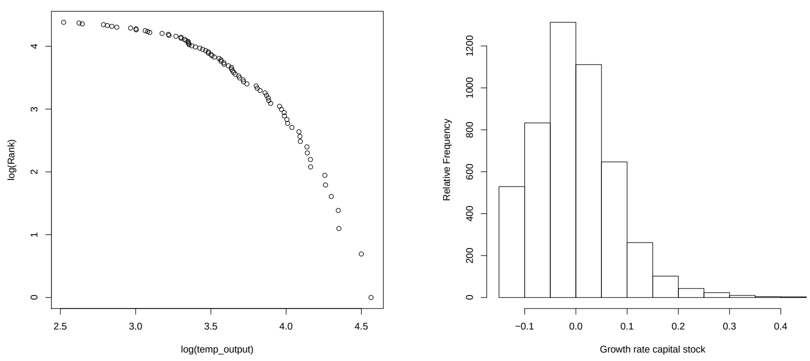


Figure 23: Beveridge curve (a) and Phillips curve (b).

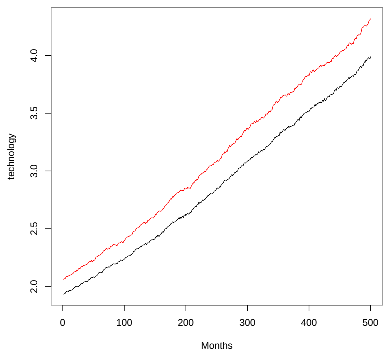


(a) (b)

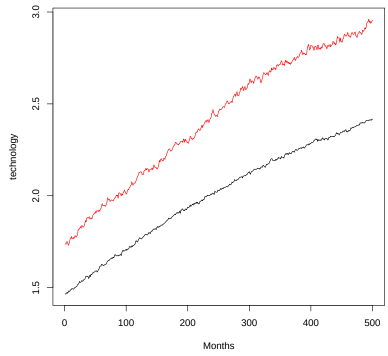
Figure 24: Firm size distribution (measured bx firm output) after 500 months (left). Annual growth rates of firms' capital stock (right).

Table 7: Quarterly cross-correlation structure of bandpass filtered time series of the business cycle and various macroeconomic variables based on 10 batch runs. Standard deviations in parentheses.

	t-4	t-3	t-2	t-1	0	t+1	t+2	t+3	t+4
Output	-0.267	0.134	0.551	0.872	1.000	0.872	0.551	0.134	-0.267
	(0.106)	(0.093)	(0.055)	(0.017)	(0.000)	(0.017)	(0.055)	(0.093)	(0.106)
Consumption	-0.495	-0.189	0.217	0.618	0.893	0.935	0.743	0.382	-0.037
	(0.090)	(0.097)	(0.086)	(0.055)	(0.027)	(0.023)	(0.057)	(0.106)	(0.141)
Investments	-0.334	-0.130	0.144	0.436	0.679	0.791	0.741	0.529	0.202
	(0.153)	(0.197)	(0.214)	(0.196)	(0.151)	(0.095)	(0.055)	(0.068)	(0.106)
Unemployment	0.408	0.024	-0.403	-0.760	-0.948	-0.895	-0.646	-0.280	0.099
	(0.101)	(0.091)	(0.057)	(0.024)	(0.015)	(0.038)	(0.083)	(0.124)	(0.138)
Vacancies	-0.152	0.160	0.481	0.729	0.828	0.721	0.458	0.116	-0.213
	(0.136)	(0.128)	(0.114)	(0.103)	(0.102)	(0.115)	(0.123)	(0.108)	(0.071)
Productivity	0.316	0.090	-0.156	-0.367	-0.500	-0.528	-0.457	-0.318	-0.146
	(0.170)	(0.185)	(0.190)	(0.189)	(0.186)	(0.175)	(0.162)	(0.154)	(0.152)
Price	-0.011	-0.026	-0.040	-0.042	-0.032	-0.019	-0.017	-0.017	-0.014
	(0.101)	(0.096)	(0.099)	(0.109)	(0.120)	(0.129)	(0.130)	(0.117)	(0.091)
Wage	0.592	0.445	0.212	-0.059	-0.314	-0.495	-0.581	-0.566	-0.464
	(0.108)	(0.119)	(0.137)	(0.156)	(0.176)	(0.191)	(0.19)5	(0.183)	(0.162)
Total Credit	0.098	0.383	0.631	0.778	0.777	0.598	0.300	-0.042	-0.348
	(0.157)	(0.145)	(0.117)	(0.084)	(0.064)	(0.074)	(0.087)	(0.095)	(0.102)
Leverage Ratio	0.028	0.340	0.622	0.800	0.822	0.658	0.363	0.013	-0.310
	(0.184)	(0.174)	(0.137)	(0.090)	(0.056)	(0.060)	(0.079)	(0.097)	(0.113)
Mark ups	-0.248	-0.449	-0.578	-0.596	-0.487	-0.261	0.018	0.283	0.473
	(0.199)	(0.169)	(0.133)	(0.106)	(0.092)	(0.091)	(0.103)	(0.133)	(0.166)



(a)



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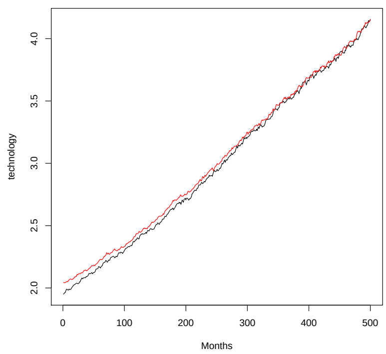

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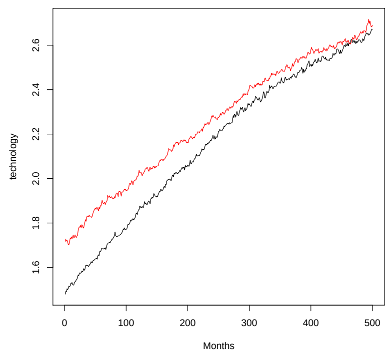

(d)

Figure 25: Upper panels: Comparison of time evolution of the regional means of firms' productivity of high-tech (red line) and low-tech (black line) firms, where the group of high-tech firms consists of all firms whose productivity is above the population median. Lower panels: Time evolution of the average productivity of those firms that are high- and low-tech firms at the beginning of the considered simulation. Left panels: Region 1; right panels: Region 2.