Spatial Skill Heterogeneity and Growth: An Agent-based Policy Analysis*

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Abstract. We develop an agent-based macroeconomic model featuring a distinct geographical dimension and heterogeneous workers with respect to skill types. Using a calibrated model it is examined in how far effects differ if policy measures aiming at an improvement of general skills are uniformly spread over all regions in the economy or focused in one particular region. We find that it depends on the level of spatial frictions on the labor market how the spatial distribution of policy measures affects the effects of the policy. Furthermore we show that a reduction in spatial frictions does not necessarily improve the growth of output and household income.

Key words: Skills, Commuting Costs, Economic Growth, Labor Market, Agent-Based Simulation

1 Introduction

Normative research in economics has traditionally been, and to a large degree still is based on the development and analysis of highly stylized, analytically tractable models. In particular for macroeconomic issues the models used for policy analysis are typically dynamic general equilibrium models that have been calibrated using empirical data. However, numerous restrictive assumptions underly most mainstream analytical models (e.g. homogeneity of individuals, perfect rationality, rational expectations, perfect ex-ante coordination in an equilibrium) and so far there exists almost no general theoretical basis that allows to judge how far findings, obtained under these simplifying assumptions, carry over to scenarios where agents are heterogeneous or out of equilibrium (see e.g. [1]). On the

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other hand, recent developments in computer technology and software engineering have made large scale simulations an increasingly powerful and attractive new approach for understanding the characteristics of economic systems and for deriving economic policy recommendations. In particular, by explicitly modelling the decentralized interaction of heterogeneous economic agents in systems like markets or organizations, *agent-based computational economics* (ACE) attempts to transcend the limitations of traditional models.

The ACE modeling approach is not only well suited for explicit consideration of heterogeneity among economic agents, but also allows for a wide range of assumptions concerning the rules that determine the behavior of individual economic agents. Existing ACE models typically consider adaptive individuals who learn how to behave and react based on their own experience and on the available information. Models of this kind have been developed in many areas of economics. Among others, they have been used to study the emergence of trading behavior on goods-markets and on financial markets, bidding behavior in auctions, numerous issues concerning innovation and industry evolution or the emergence of cooperative behavior in economic systems. Surveys over agent-based research in these areas can be found in [2].

The purpose of this paper is to demonstrate that agent-based closed macroeconomic models can be usefully applied to evaluate economic policy measures in a way that is infeasible for representative agent models. In particular, we focus on an area that has recently received strong attention by policy makers in industrialized countries, namely the question what kind of economic policy measures are best suited to facilitate innovation and diffusion of new technologies and productivity increase. Dealing with this question requires to shed more light on the interplay of processes leading to the generation of new technologies and the ability of firms to adopt such new technologies. In order to efficiently use new technologies the workforce of the industrial firms has to be able to build up the required level of specific skills and the ability to do so depends on the general skills levels of the employees. There is strong empirical evidence that the skill distribution in the workforce has substantial influence on the speed of technological change, the employment and wage dynamics and growth in an economy (e.g. [3]). Therefore, policies aiming at a change in the local skill distribution play an important role in fostering technological change and growth.

In that respect spatial aspects also play a crucial role. First, in many industrialized countries there are strong regional differences in the skill and knowledge distribution where high-skill employees are strongly concentrated in a few areas. Second, geographic proximity between firms has a crucial impact on the intensity of technological spillovers between them. Both theoretical and empirical studies of innovative activities have demonstrated the importance of technological spillovers for industry development (see e.g. the surveys by [6] and [7]). Whereas the main channels through which technological information flows between firms depends heavily on the type of industry considered a considerable role in establishing technological spillovers is typically assigned to direct communication and the flow of skilled and well informed employees. Therefore, the interaction of firms and employees on the (local) labor market is of great importance for the size of technological spillovers and, hence, for innovative activities. Taking into account regional differences and the existence of (*local*) knowledge flows between firms the question arises to what extent economic policy measures should be regionally differentiated. In particular, it has to be explored how the effects of certain skill enhancing policy measures differ when applied in regions with different characteristics. Furthermore, the right allocation of policy measures among all regions in the economy is a difficult problem. Should the activity be centered on the strongest or on the weakest region or should all measures be uniformly distributed across regions? The type of insights about crucial medium and long run effects we can generate using our model allows policy makers to get a broader picture of the implications of different allocations of public funds and therefore provides an important contribution to policy advice.

In this paper we analyze how the effects of different spatial distributions of policy measures depend on the amount of spatial frictions in the labor market expressed as commuting costs of workers who are employed outside their home-region. In the context of our two-region model we compare policies that moderately increase general skill levels of workers uniformly across regions with an alternative approach where all efforts are concentrated in one region and skills there are upgraded to a very high level whereas the skill distribution in the other region stays unchanged. In [10] a similar comparison was discussed for the case where high commuting costs make it exceptional for a firm to hire workers outside its region. Using the same simulation model we employ here it was shown that a uniform spatial distribution of policy measures leads to better long run outcomes in terms of output growth than a spatial concentration of efforts. Here we focus on the opposite case where spatial frictions are low. We consider on the one hand a case without any commuting costs as a benchmark and on the other hand compare the two types of policies for small but positive commuting costs. It turns out that the size of the commuting costs indeed has crucial impact on relative performance of the different policy types. Without commuting costs no significant differences between the effects of the policy types emerge whereas for small commuting costs the performance of the spatially concentrated policy is better than that of the uniform one, which is qualitatively different from the results for high commuting costs presented in [10].

We proceed as follows. The main features of the simulation model are described in section 2. In section 3 we present the results of our policy experiments and we conclude in section 4 with a brief discussion of our results and the policy implications.

2 Short description of the model

Our model is a closed model consisting of an investment (or capital) goods, a consumption goods, and a labor market. Agents are distributed over $R = 2$ regions where some markets (consumption goods) are assumed to be local, some are global (investment goods) and workers might commute for work to employers in neighboring regions at certain costs. Investment goods are supplied at an exogenously given price. The inputs for consumption good production are investment goods and labor. Process innovation improves the quality of investment goods leading to higher productivity of capital in the consumption good production. Consumption goods are sold at malls. Malls are not treated as profit-oriented enterprizes but simply as local market platforms where firms store and offer their products and consumers come to buy goods at posted prices. The labor market hosts workers of different types. They are differentiated along their general as well as their specific skill level. A crucial assumption is that sufficient specific skills of workers are needed to exploit the full potential of the advanced technological level of investment goods like production machines. Put formally, there is complementarity between the average quality of the investment goods of a firm and the average level of specific skills of its employees with respect to the productivity in consumption good production. Empirical evidence for such complementarity can for example be found in [9]. Workers increase their specific skills when working in a firm where the quality of the capital stock is higher than their current level of specific skills. Higher general skills of a worker imply faster adaptation in terms of his specific skills

Two types of active agents and two types of passive agents (in the sense that this type of agent does not take any decisions) are present in the model.

Page constraints prevent us from giving a detailed description of all relevant interaction protocols and decision rules of the model. We refer to [10] for a more detailed discussion in this respect. Here we just briefly list the main activities and decision processes driving the dynamics of our model.

- Consumption good producers build expectations about future demand using past observations of sales. Based on these expectations production quantities and the corresponding demand for capital and labor are determined.
- If a firm has a positive demand for capital it purchases the needed amount from the (unique) global supplier of the capital good thereby improving the average quality of its capital stock.
- If a firm has a positive demand for labor, vacancies are posted where in the announcement the wage to be paid by the firm is given.
- Workers searching for jobs (these are the unemployed plus a certain fraction of on-the-job searchers) see posted vacancies and apply to the ones with the highest offered wages if the wage offers exceed the current reservation wage of the worker. In case the offered position is outside the home region of the worker commuting costs *comm* are subtracted from the offered wage.
- Firms select among all applicants for a vacancy those with the highest general skills and employ them.
- While being employed each worker adjusts his specific skills to the average quality of the capital stock of his employer. The adjustment speed depends positively on the general skills of the worker. The productivity of a firm is given by the minimum of the average quality of its capital stock and the average level of the specific skills of its employees.

– Workers use their labor income to save and buy consumption goods. In each region there is one local mall where consumption good producers from all regions might offer their goods at posted prices. It is assumed that transportation costs of consumption goods across regions are negligible. Consumers (=Workers) make their purchasing decisions based on the posted prices using a stochastic rule as described in a standard logit model.

Most of these actions are repeated on a monthly basis and whenever we refer to one time-period by default we mean one month.

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

Apart from the fact that behavioral rules of individual agents in the model have to be in accordance with stylized representations of standard decision rules employed by their real-world representatives, it is also important to critically examine the plausibility of the used parameterization and the qualitative patterns of simulation results. Concerning parametrization it is important to employ empirical insights with respect to all model parameters where direct evidence exists. We follow this approach and calibrate the parameters in our model using estimates from different streams of relevant literature (see [10] for details). Concerning model evaluation a widely used approach in recent work in agent-based economics is to compare simulation outcomes with 'stylized facts' that have been established using real world data. This kind of comparison is supposed to restrict the range of model parameters and to improve the confidence that the model captures crucial aspects of interactions in the sectors considered in the model, see [8] for a discussion of approaches to validate agent-based simulation models. Our model reproduces several stylized facts, but due to space constraints this cannot be elaborated here.

3 Policy experiments

To set up our policy experiments we consider three different types of regions with respect to the distribution of general skills in the workforce. In our simulation there are five potential levels of general skills for a worker and in a *low skill* region the skill distribution is such that 80% of workers have the lowest general skill level, whereas the remaining workers are equally distributed across the other four levels of general skills. Analogously, a region is a *medium skill* or *high skill* regions if 80% of workers have general skill level 3 respectively 5.

In our policy experiment we consider an initial condition where both regions in our economy are low skill regions and a policy maker intends to invest in the upgrading of general skills in the economy. Due to financial constraints it is not possible to upgrade both regions to high-skill regions. Rather the policy maker has to choose between two options. Either both regions can be upgraded to medium skill or efforts are concentrated in region 2 thereby moving this region to high skill whereas the skill distribution in region 1 stays unchanged. We examine the effects of these two types of policies for two different scenarios characterized by the level of commuting cost. On the one hand, we consider the scenario where commuting costs are zero ($comm = 0$) and in the second scenario we set commuting costs to 5% of the initial wage level in the economy ($comm = 0.05$), which we consider as a positive but low level of commuting costs.

In order to address this question we have run batches of 50 simulation runs for the *uniform medium* and *low-high* scenarios and compare them with each other and with the base case of uniform low-skill regions. In figure 1 we compare mean trajectories of output over the 50 runs in the three cases for $comm = 0$ and $comm = 0.05$. Each simulation is run for 200 months, which corresponds to about 17 years. The economy consists of two regions where in each region 5 consumption good producers and 200 workers/households are located.

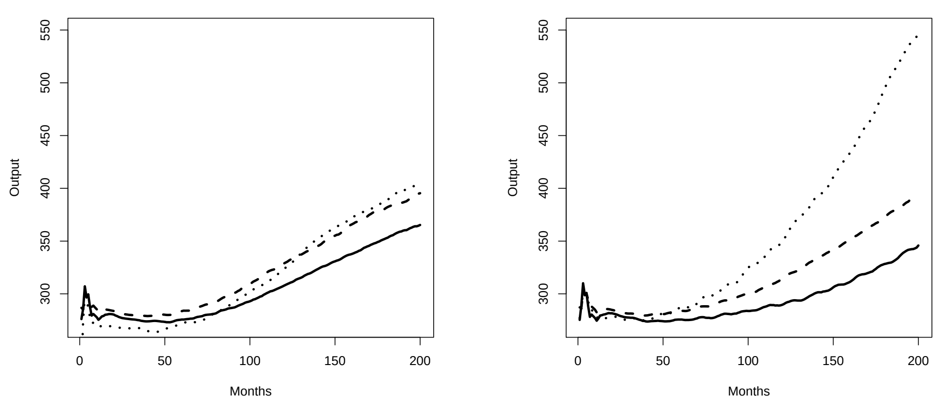

Fig. 1. Batch run with zero (left panel) and low (right panel) commuting costs for outputs in uniform low scenario (solid line), uniform medium scenario (dashed line), and low/high scenario (dotted line);

It can be clearly seen that the relative performance of the two different types of policy distributions depends crucially on the level of commuting costs. If commuting costs are zero, which means that there exists a global labor market without spatial frictions, no significant difference in output growth between the uniform medium and the low/high scenario can be detected. In both cases the policy induced increase in general skills leads to an improved growth rate compared to the uniform low scenario. Quite a different picture emerges for low positive commuting costs. Here the growth rate is substantially larger in the low/high scenario than in the uniform medium scenario and also substantially larger than the growth rate in the low/high scenario without commuting costs. This finding is remarkable for two reasons. First, it is qualitatively opposite to the effects of the different policy types if commuting costs are large. As discussed in [10] for large commuting costs a uniform distribution of skill upgrading measures leads to higher growth than a spatially concentrated policy. Second, if the spatially concentrated policy is implemented the introduction of small spatial frictions on the labor market actually improves performance compared to a frictionless global labor market. Both observations are at first sight surprising and demonstrate the non-linear and path-dependent nature of the relevant economic processes.

In order to get a better understanding of the economic mechanisms responsible for relative performance of the two policy types we examine in more detail the features of the dynamics of several key variables in the low/high scenario. We always simultaneously consider the cases $comm = 0$ and $comm = 0.05$, since such a comparison highlights the mechanisms that are driving the results.

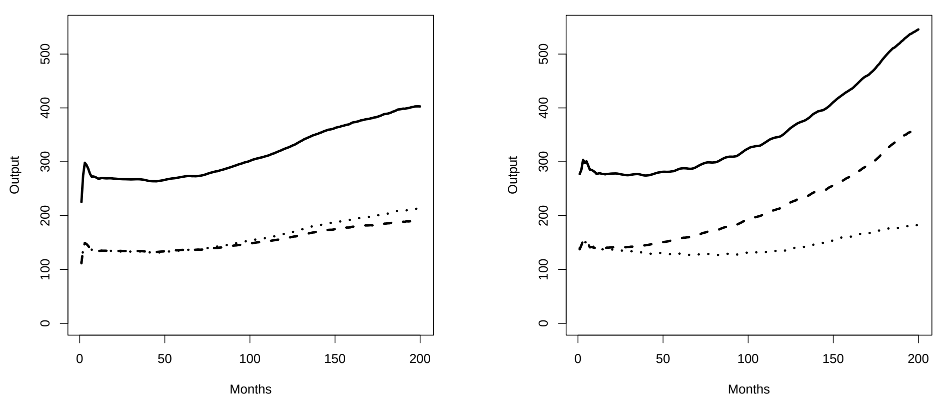

Fig. 2. Batch runs for zero (left panel) and low (right panel) commuting costs; total outputs (solid line), output in the low skill region (dashed line), output in the high skill region (dotted line);

Figure 2 shows the dynamics of the aggregate output of producers in the low skill region 1 and the high skill region 2. Whereas with no commuting costs both regions produce about the same output, in case of low commuting costs the low skill region exhibits a strong growth in output over time and at the end of the considered time interval of 200 months produces about double the output of the high–skill region. To understand why the output of the high skill region is not larger than that of the low skill region, it has to be kept in mind that the terms high and low skill regions refers to the skills of the workers living in a certain region rather than to the skills of workers working in a certain region. As can

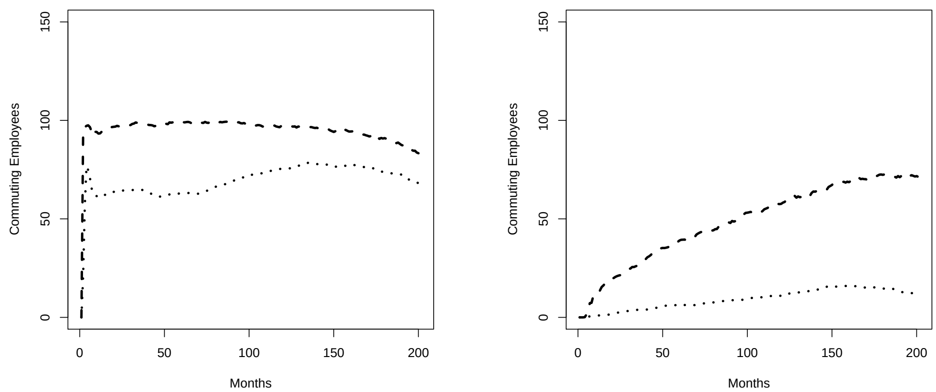

Fig. 3. Batch runs for zero (left panel) and low (right panel) commuting costs; number of commuters from low to high skill region (dotted line), number of commuters from high to low skill region (dashed line);

be seen in figure 3 in both scenarios a substantial number of high-skill workers commute to the low-skill region and work for producers located there. In case of no commuting costs almost half of the high skill workers commute throughout the entire time interval of 200 periods, so the number of high-skill employees in both regions is almost identical which also explains the relatively homogeneous output quantities across the two regions. Also, without commuting costs there is a substantial number of commuters from the low-skill to the high-skill region. As has to be expected the introduction of small commuting costs reduces the flow of commuters in both directions, where the number of commuters from the high- to the low-skill region is still substantial and increasing over time. On the other hand, the flow from the low- to the high-skill region becomes very small. So, a first observation to be made is that as well with zero as with small commuting costs substantial transregional spillovers through the labor markets emerge and both regions profit from the general skill level of workers in the high skill region.

The fact that these spillovers have a much more positive effect in the low skill region if commuting costs are positive is due to the different demand dynamics emerging for different commuting costs. Differences in demand for goods produced in the two regions are triggered by price differences which again are driven by wage differences in the two regions. In case of a global labor market no systematic wage differences between the two regions emerge and as can be seen in figure 4 there are no significant price difference between the goods

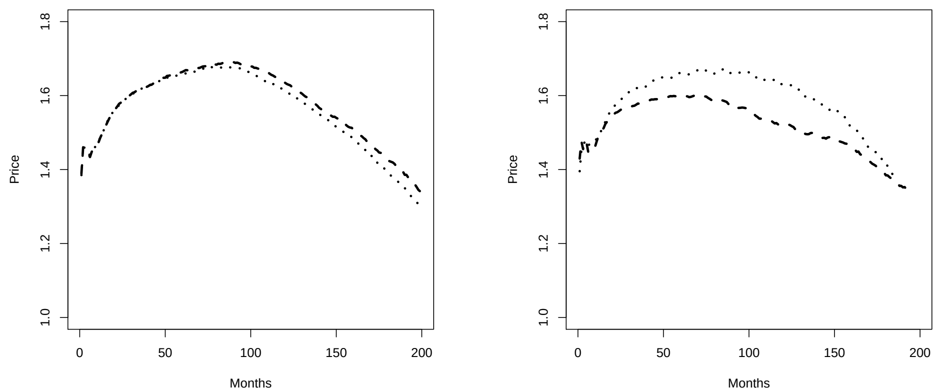

Fig. 4. Batch runs for zero (left panel) and low (right panel) commuting costs; prices in the low skill region (dashed line), prices in the high skill region (dotted line);

produced in the two regions. In the case of positive commuting costs systematic price differences emerge after a short initial phase, where products from the low-skill region are cheaper than those from the high-skill region. The reason is that initially the number of commuters from the high- to the low-skill region is small and therefore the vast majority of workers with high general skills work for producers in the high-skill region. On the one hand, this leads to a faster wage dynamic in that region because employers have preferences to hire high-skilled workers and therefore these workers are more likely to carry out successful on-the-job searches, thereby increasing their wages[1]. On the other hand, initially the difference in specific skills between workers with different levels of general skills are small and therefore producers in the high-skill region have higher unit-costs than those in the low-skill region. This translates to the observed price difference and due to this price difference demand shifts towards the goods produced in the low skill region. Producers in that region react to the increasing demand by investing in new capital stock (see figure 5, which due to the assumed

[1] Due to space constraints we do not present the graph that demonstrates the wage differences between the regions.

technological progress in the investment good sector also improves the quality of their capital stock and increase their productivity. This is a self-reinforcing process because improvements in productivity reinforces the price advantages of producers from the low-skill region and generates additional positive demand effects. At the same time the output expansion of producers from the low skill region leads to a transfer of high-skilled workers from the high- to the low-skill region (see figure 3). The reason that we can see a flow of high-skilled workers from the high- to the low-skill region despite of the fact that the average wage level in the high-skill region is higher, is that due to the falling demand for goods produced in the high-skill region labor demand goes down there and high-skilled workers become unemployed. Indeed the capital and labor investment process triggered by the price heterogeneity is the crucial mechanism responsible for the high growth of the low-skill region output. As can be seen in figure 5 no net investment of capital emerges in the case without commuting costs where price stay almost homogeneous throughout the run.

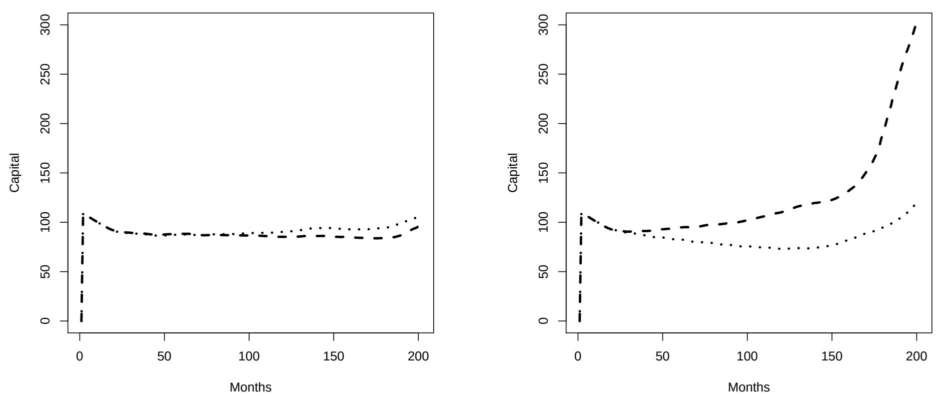

Fig. 5. Batch runs for zero (left panel) and low (right panel) commuting costs; capital stock in the low skill region (dashed line), capital stock in the high skill region (dotted line);

The chain of effects we have discussed above implies that with positive but low commuting costs a self-reinforcing cycle of capital and labor investments by producers from the low-skill region arises which implies that output in that region grows fast and is larger than output in the high-skill region. This however does not imply that in such a scenario the low-skill region also has an advantage with respect to regional income and consumption. As can be seen in figure 6 labor income is in both scenarios larger in the high-skill than in the low skill region, where the difference is smaller in the presence of small positive commuting costs. This of course is due to the fact that high-skilled workers earn higher wages than low-skilled ones regardless of where they are employed. An interesting observation to be made in figure 6 is that labor income in both regions goes up as the commuting costs increase from zero to a positive level. Accordingly, for $comm = 0.05$ total output in the economy and labor income in both regions are larger than in the absence of spatial frictions in the labor market.

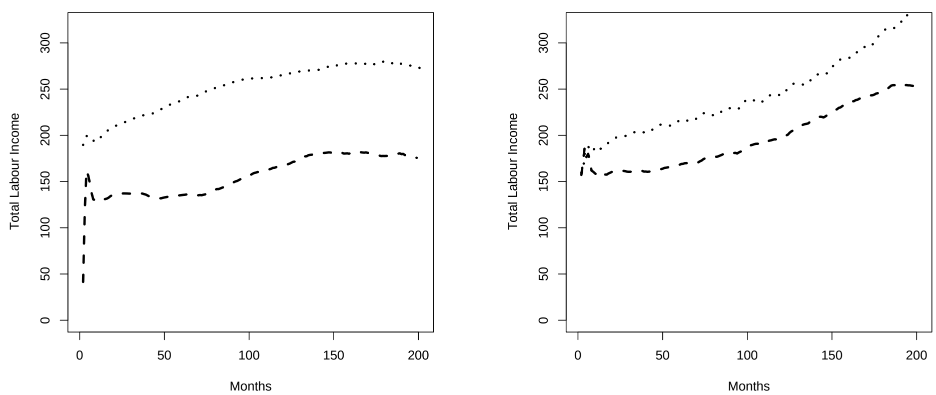

Fig. 6. Batch runs for zero (left panel) and low (right panel) commuting costs; total labor income of workers in the low skill region (dashed line) and the high skill region (dotted line);

4 Policy Implications and Discussion

In this paper we have used an agent-based spatial macroeconomic model describing the interaction between goods and labor markets to examine the question how the effects of different spatial concentrations of economic policy measures depend on spatial frictions in the labor market. In particular, we have compared scenarios where general skills of workers are upgraded uniformly across regions with regionally concentrated upgrading. It has been shown that in the absence of commuting costs the spatial distribution of the policy measures does not significantly affect their impact. However, if commuting costs are positive but low than a spatially concentrated policy performs better than a uniform approach. In case such a policy is applied the existence of spatial frictions has positive effects on total output in the economy and on labor income in both regions. These positive effects are due to the combination of technological spillovers to the low-skill region through the labor market and demand induced investment incentives for producers in that region. As has been shown in [10] the advantages of the spatially concentrated policy disappear if commuting costs become larger and the technological spillovers are reduced.

These insights have several policy implications. First, they clearly demonstrate that the optimal spatial distribution of policy measures depends crucially on the spatial frictions in different markets. As our results demonstrate the effect of an increase in a parameter like the commuting costs is not always monotonous and therefore a good estimate of such frictions is needed to give sound policy advise. Second, if we take the spatial skill distribution as given and consider policy measures aiming at the reduction of spatial frictions on the labor market, our findings suggest that in cases where skill distributions differ between regions it is desirable to reduce commuting costs to a level where substantial spillovers between regions through the labor market can arise, but it is not necessarily desirable to completely eliminate the spatial frictions. The finding that the existence of frictions can have positive macroeconomic effects is to our knowledge an innovative observation in this type of literature. As has been demonstrated in our discussion above it is due to the combination of the explicit consideration of agents' heterogeneities and of the path dependencies of transient dynamics on the goods and labor market. In that respect we feel that these observation very well illustrate the potential of agent-based models to produce innovative insights into economic dynamics and policy design.

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