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THE EFFECT OF PROJECT FUNDING ON INNOVATIVE PERFORMANCE AN AGENT-BASED SIMULATION MODEL

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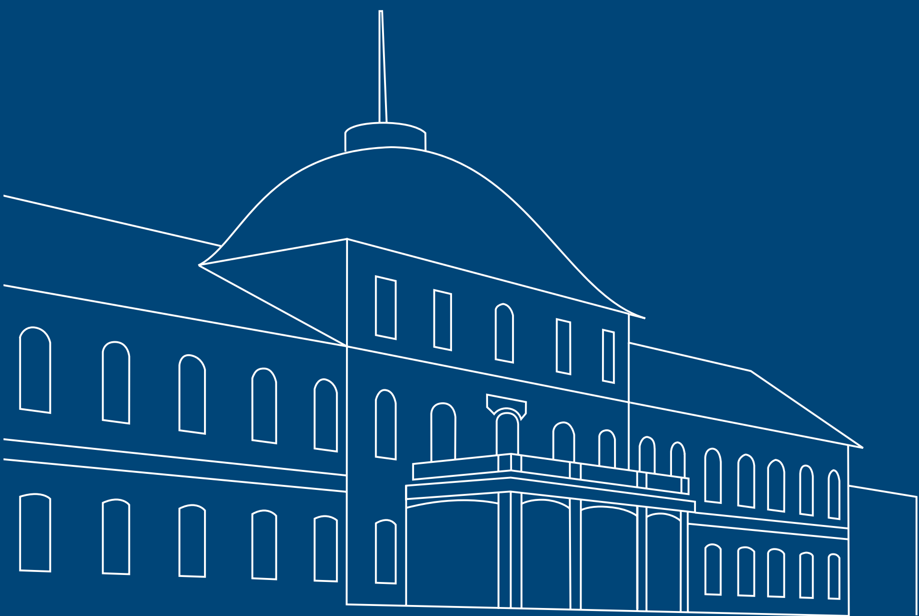

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Abstract

Analyzing the effect of Direct Project Funding (DPF) on innovative performance of economic agents is a major challenge for innovation economists and policy makers who must give valid policy recommendations and decide on the allocation of financial resources. An approach that becomes more and more important is the use of agent-based modeling in analyzing innovative performance of market players. In this paper, an agent-based percolation model is used to investigate the effects of project funding on innovative performance in terms of the maximum technological frontier that can be reached as well as in terms of the number of innovations generated by firms. The model results show that firms which participate in subsidized projects outperform firms that do not participate in subsidized projects, especially in increasingly complex technological fields. However, the worse performance of firms that do not participate in subsidized projects can be offset by an increase in the firms' financial resources. Hence, the model indicates, the effect of project funding is a purely financial one and might even have negative effects on innovative performance. This is the case if, for instance, a high number of funded research projects disturbs firms' paths through the technology space. Following the results of the model, project funding is most effective and important in increasingly complex technology spaces and less effective and important in less complex technology spaces. Moreover, the model results show, other financial resources as venture capital can substitute for direct project funding

Key words: project funding, innovation, technology space, agent-based simulation

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1 Introduction

Growing international competition, emerging global challenges as sustainable urban development and increasing complexity of products and services force today's economies to be as innovative as possible to stay competitive. As a result, to permanently increase firms' innovative performance is a major challenge for firms and policy makers in Germany. To foster this innovative performance, the German Federal Government supports German companies, research institutions and universities by spending more than 80 billion Euro (3% of its GDP) on research and development [BMBF, 2014e, p. 18]. One instrument used by the government to keep Germany's leading position is the promotion of joint research efforts of firms, universities and research institutions by direct project funding (DPF). The overall goal of direct project funding is to improve firms' innovative performance to guarantee long-term growth [BMBF, 2014f, prologue]. However, it is not a priori clear that project funding is the right instrument to achieve this ambitious goal. Studies show that the effects of DPF on innovative performance are not only positive, but can also be negative [Aschhoff/ Sofka, 2009; Czarnitzki et al., 2007; Czarnitzki/ Hussinger, 2004; Fornahl et al., 2011; Hsua/ Hsueh, 2009]. On the one hand, project funding is an additional financial resource that does not only prevent the underinvestment in complex technological fields, but can also help to 'guide' firms through the technology space and foster research in predefined 'socially desirable' fields. On the other hand, project funding costs billions of Euro and might even negatively influence firms' natural trajectories as well as it might prevent market players from other useful investments by changing their behavior. In addition, government should intervene in the market only where it is absolutely indispensable [Gabler, 2014]. Therefore, to evaluate policy intervention in terms of direct project funding is of utmost importance. This evaluation is necessary to show whether the positive effects of project funding can outweigh its negative effects as well as to make project funding effective and efficient. Only by doing so, researchers can legitimize public actions and help politicians to take decisions that foster future development. As policy evaluation is such an important topic, this paper uses an agent-based model for answering the following question: 'What are the effects of 'direct project funding' (DPR) on firms' innovative performance?'. The agent-based percolation model used in this paper extends the percolation model of Silverberg/ Verspagen [2007] by incorporating subsidized R&D projects that influence the paths firms choose through the technology space.

The paper is structured as follows: The second chapter provides the reader an overview of how and why the German Federal Government uses project funding as an instrument of market intervention, why the particularities of innovation processes cause problems in innovation research and how the method of agent-based modelling can help to solve these problems. In the third chapter, the agent-based percolation model built to answer the research question named above is presented and the simulation is explained in detail. The fourth chapter presents the simulation results and compares the results of the basic model to the results of the model with subsidized R&D projects. In the last, the fifth chapter, the model results of this paper are summarized and a conclusion as well as an outlook is given.

2 Theoretical Background

The way in which innovation processes and the search for new knowledge take place has changed. Today's economies and sectors become more and more connected and interlinked. Collaborations across institutional forms and organizational boundaries are common practice [Powell/ Grodal, 2005, p. 57]. "[C]omplex networks of firms, universities, and government labs are critical features for many industries" [Powell/ Grodal, 2005, p. 58]. This leads to a situation in which "innovation is shifting away from individual firms towards territorial economies and the distributed networks by which they are linked" [Herstad et al., 2013, p. 495]. Hence, joint research efforts and interorganizational knowledge exchange are of growing importance for the competitiveness of firms and sectors [Herstad et al., 2013, p. 495]. Therefore, Germany as a knowledge-intensive economy tries to foster both national and international interdisciplinary joint research efforts between different actors in the economy [BMBF, 2014e, p. 30]. How important such research efforts actually are to the German government can be seen by the mere fact that the German Federal Government aims at spending more than 80 billion Euro (3% of its GDP) on research and development [BMBF, 2014e, p. 18]. In fact, thirty percent of all spending on R&D in Germany is provided by the public sector [BMBF, 2014d]. This public research funding essentially consists of "institutional funding, goal-oriented project funding and the funding of departmental research" [BMBF, 2014d]. The goal-oriented project funding or the so-called direct R&D project funding provides firms, universities and research institutions the opportunity to participate in (joint) research projects that are subsidized by the German Federal Government.

As institutional or departmental research funding, the overall objective of project funding is "to maintain and build on the competitive advantage and excellent reputation of German research" [BMBF, 2014f, prologue]. However, the main advantage of direct project funding in comparison to departmental or institutional funding is that project funding can motivate firms, universities and research institutions to focus on relevant technological problems and to prioritize economically and socially desirable research fields [Spectrum, 1999]. Therefore, subsidized projects are located at concrete research areas and are implemented within a framework of different research programs [BMBF, 2014d], to support the development of key technologies in pre-selected key application areas [Aschhoff, 2009, p. 1]. The funding of key application areas, for instance, aims at solving global challenges, especially in the fields of climate and energy, health and nutrition, mobility, security and communication [BMBF, 2014a]. The funding of key technologies, for instance, in automotive, medical technology, engineering and logistics, complements this funding effort [BMBF, 2014a,b].

According to economic theory, government has to intervene in the market as the public good features of knowledge lead to market failure. Following this argument, project funding has to subsidize projects in fields in which firms would not invest without additional financial resources. These are, for instance, fields that are highly complex and therefore too expensive to explore if the external effects are not internalized [Aschhoff, 2009, p. 1]. Even though the theoretical argument why project funding is an important instrument is convincing, it still has to be questioned whether such policy intervention actually can achieve its ambitious goals. "In the face of shrinking government budgets and intensified international competition in the field of technology, knowing and increasing the efficiency of innovation policies has become crucial" [Aschhoff, 2008, p. i]. Therefore, it has to be asked whether the instrument of project funding promotes 'additionality', i.e. to what extend this instruments promotes additional

R&D activities and to what extend it simply subsidizes activities that already take place (windfall-profits).

As project funding affects different micro-, meso- and macroeconomic aspects which are in an interdependent relationship, the effects of project funding on firms' innovative performance can be both positive and negative. Because of these diverse effects, recent literature has evaluated the effect of direct R&D project funding on, among others, innovative performance [Czarnitzki et al., 2007; Czarnitzki/ Hussinger, 2004; Fornahl et al., 2011; Hsua/ Hsueh, 2009], private R&D spending [Almus/ Czarnitzki, 2003; Aschhoff, 2009; Czarnitzki/ Fier, 2001; Czarnitzki/ Hussinger, 2004], firms' productivity [Colombo et al., 2011] as well as labor demand and employment [Ali-Yrkkö, 2005; Ebersberger, 2004]. While many studies investigate a potential crowding-out effect of public R&D subsidies, little has been written about the effect of publicly subsidized R&D projects on innovative performance of firms, universities and research institutions. If investigated, studies mainly measure the effect of project funding on innovative performance in terms of patent applications [Czarnitzki et al., 2007; Czarnitzki/ Hussinger, 2004; Fornahl et al., 2011]. As expected, the studies show that the effect of subsidized research projects on innovative performance is ambiguous and can be dependent on different aspects as firms' size, industry, technology novelty and ratio of public subsidy to firms' own R&D budget [Hsua/ Hsueh, 2009]. Czarnitzki/ Hussinger [2004] show, that publicly sponsored research projects indeed stimulate firms' patenting activities. Czarnitzki et al. [2007] highlight that project funding has a positive effect on firms' patenting activities, but only in Finland and not in Germany. Fornahl et al. [2011] found out that project funding can increase firms' patent applications, but only if government subsidizes joint research projects. Aschhoff/ Sofka [2009] found out that public funding for innovation projects does not have any significant effect on innovative performance in terms of market success. Hsua/ Hsueh [2009] show, that public R&D projects have a positive effect on the technical efficiency of such projects, but the effect is dependent on different aspects, e.g. the effect is bigger for small firms. None of these studies, however, investigates the effect of research funding on the innovative performance of a research network consisting of firms, universities and research institutions. Summing up, it has to be guaranteed that project funding does not waste resources, but leads to a situation that is socially and economically preferable. Therefore, the quantitative and qualitative evaluation of subsidized research projects is important for both policy makers and researchers as well as for the society as a whole.

However, the main problem with the evaluation of policy intervention in innovation processes are the particularities of innovation processes as true uncertainty, bounded rationality, imperfect information, heterogeneity, non-linear relationships, punctuated equilibria, as well as both quantitative and qualitative change [Dawid, 2006; Pyka/ Fagiolo, 2005; Silverberg/ Verspagen, 2007]. These particularities, however, are at odds with neoclassical assumptions of representative, homogeneous, perfectly rational and informed agents. Hence, the traditional toolkit of economics is inadequate to analyze innovation processes [Dawid, 2006; Pyka/ Fagiolo, 2005; Silverberg/ Verspagen, 2007]. Besides the fact that classical models often hinge on these over-simplifying, ad-hoc assumptions that are at odds with reality [Pyka/ Fagiolo, 2005, p. 6], these models are also inadequate to analyze innovation processes as they "show a limited attention to empirical validation and joint reproduction of stylized facts" [Pyka/ Fagiolo, 2005, p. 7]. However, even though traditional models are insufficient for analyzing innovation processes, this does not mean that such processes cannot be analyzed in general.

As innovations are not completely random and unrelated, but as there are empirical facts and patterns that can be observed [Dawid, 2006; Silverberg/ Verspagen, 2005], there exist possible methods and tools to investigate innovations. One method that is relatively new in the field of innovation policy evaluation, but does not hinge on neoclassical assumptions and is able to incorporate empirical facts and patterns of innovations processes, is the method of agent-based modeling in general and agent-based percolation models in particular.

Agent-based modeling becomes more and more important in innovation economics as it allows to model and analyse complex systems with autonomous, decision-making agents that interact with each other and with their environment [Garcia, 2005; Macal/ North, 2007]. In contrast to homogeneous, representative agents with perfect knowledge, agents in an agent-based simulation act autonomous and independently in their environment. They are equipped with a kind of social ability that allows them to communicate with other agents, they act goal-directed to achieve a certain goal and they are flexible and can adapt their behavior to other agents' behavior and their environment [Macal/ North, 2007, p. 96]. ABM can help to not only understand agents' or individual's behavior, but also to understand aggregate behavior and how the behavior and interaction of many individual agents leads to large-scale outcomes [Axelrod, 1997, p. 4]. The behavior that is modeled in this paper follows the basic idea of percolation theory.

"Percolation theory is the study of an idealized random medium in two or more dimensions. Percolation models describe and investigate the percolation of a medium as, for instance, liquid or gas through a porous surface [Shante/ Kirkpatrick, 1971, p. 326]. In a percolation model, the fluid flows along oriented or unoriented paths where some bonds are accessible and some bonds are blocked and therefore inaccessible [Shante/ Kirkpatrick, 1971, p. 328]. The percolation probability in a model with bond percolation describes the probability that an edge between two cells is 'open' such that a medium, as, for instance, water, can pass from one lattice cell to another [Grimmett, 1997, p. 147]. Using these models and the percolation probability one can investigate if and how 'easy' a medium can pass through a certain surface, dependent on the kind of surface[1].

Already in 1991, Mort [1991] investigated the applicability of percolation theory to innovation processes. He found out that "the spread of innovations may be profitably considered as one manifestation of percolation phenomenon" [Mort, 1991, p. 37/ 38]. Nowadays, economists, as for instance Silverberg/ Verspagen and Goldschlag, make use of this theory to investigate how (the medium) firm moves through the (surface) technology space, dependent on certain characteristics of the surface, e.g. dependent on the complexity of the technology space. Questions that such models can possibly answer are: "How easy can firms move through the technology space, if the technology space becomes increasingly complex?" or "What model parameters can help firms to percolate goal-directed through the technology space, if this space is very complex?". By using such an agent-based percolation model of innovation processes, Silverberg/ Verspagen [2005] were able to endogenize the creation of technological trajectories, to replicate empirical facts of innovation processes and to investi-

[1] For a deeper insight in Percolation Theory in Physics and Mathematics see: Shante, V. K. S./ Kirkpatrick, S. (1971), An introduction to percolation theory, Advances in Physics, p. 325 - 357, 1971, Grimmett, G. (1997), Percolation and Disordered Systems, Originally published in: Ecole d'Eté de Probabilités de Saint-Flour XXVI, 1996, 141 Lecture Notes in Mathematics, Vol. 1665, p. 153 - 300, Springer-Verlag Berlin Heidelberg, 1997 and Grimmett, G. R. (1999), Percolation, Grundlehren der mathematischen Wissenschaften, Volume 321, 1999.

gate how the efficiency of different search strategies varies with technological opportunities. In addition, in their paper in 2007, Silverberg/ Verspagen [2007] incorporated economically motivated endogenous search effort and found out that this self-organized search effort might even have negative effects on innovative performance, if firms focus solely on "hot 'lodes' of technological richness" [Silverberg/ Verspagen, 2007, p. 227]. Goldschlag [2013] used an agent-based percolation model to investigate the effect of patents (that block certain cells, i.e. make them inaccessible for the medium firm) on firm's innovative performance, dependent on the complexity of the surface technology space. His results showed that monopoly power of firms can substitute for patent protection and that patents mainly improve innovative performance in situations with little monopoly power and a sufficiently difficult technology space. Besides these percolation models, there is a broad range of further issues in innovation economics that is addressed with (agent-based) percolation models, as for instance eco-innovation diffusion [Cantono/ Silverberg, 2009], the diffusion of innovation in different networks [Zeppini/ Frenken, 2013] or the flow of knowledge and its relationship to innovation [Popescul, 2012].

3 The Model

The model of innovation presented in this paper[2] is based on the work of Silverberg/ Verspagen [2007] as well as on the work of Goldschlag [2013]. The model uses the idea of economically motivated endogenous search effort of Silverberg/ Verspagen [2007] and extends their model by incorporating subsidized R&D projects that influence the different paths agents choose through the technology space, which is inspired by the work of Goldschlag [2013].

The underlying idea of this model is that agents 'percolate' through the technology space to choose technological regions where to perform R&D and to generate innovations. Research and development is costly, but agents are rewarded for successful innovations and agents can use paths of other agents and benefit from knowledge-spillovers. In the model, the ways or paths agents choose through the technology space are dependent on the technology space itself and on the motivation agents have to move through the technology space. In the following section, the technology space is explained in more detail, which is followed by an explanation of how and why agents percolate through the space and perform R&D in a basic model and in a model with project funding.

3.1 Technology Space

In the model we assume a two-dimensional technology space. The horizontal dimension represents different fields of technology or the "universe of technological niches" [Silverberg/ Verspagen, 2005, p. 214] with neighbouring columns being technologically more closely related. As in the model of Silverberg/ Verspagen [2007], the technology space wraps horizontally and thus is like a vertical cylinder which makes the left and the right edges column neighbours. The vertical dimension of the space represents the fitness of a given technology, such that higher cells in one technological niche represent a technology that is fitter. Hence,

[2]The model presented in this paper was built with the free-of-charge software NetLogo that can be downloaded here: https://ccl.northwestern.edu/netlogo/. For the model code, please contact the author.

each lattice cell a_{ij} represents the fitness (j) of a technology of a certain technological niche (i). Lattice cells are characterized by their state s_{ij} and by their resistance value $\rho_{ij} \geq 0$.

A lattice cell can be in one of three different states; state 0, state 1 and state 2. A lattice cell in state 0 is undiscovered, i.e. the technology is unknown or not yet discovered. A lattice cell in state 1 is discovered, i.e. the technology is known by some agents, but these agents do not connect this technology to their technology stock and do not use the technology to generate innovations. Lattice cells in state 2 are both discovered and viable, i.e. the technology is known and used by the agents to generate innovations.

Each cell has a resistance value ρ_{ij} for row i and column j (drawn from a lognormal distribution with mean μ_ρ and standard deviation σ_ρ). The resistance value ρ_{ij} captures the amount of effort that is necessary to discover cell (i,j), i.e. it reflects the difficulty of acquiring and using the technology. In the model, agents move through the technology space by selecting cells, performing R&D on that cells, connecting these cells to their baseline and being rewarded for successful innovations. Agents theoretically have access to all cells with some of the cells being more difficult to access than others. How 'easy' agents can move through the technology space is dependent on the complexity of the technology space, i.e. on the cells' resistance values ρ_{ij}. The higher the resistance values, the more difficult and expensive it is for the agents to perform R&D. The technology in cell (i,j) switches from state 0 (unknown) to state 1 (known but unused) once a the agent decreases the cell's resistance value to 0. The technology in cell (i,j) switches from state 1 to state 2 (known and used) if an agent connects the technology to its baseline by an unbroken chain of discovered and viable cells. A lattice cell's resistance value can be reduced by agent's R&D investment.

One concept of the model that is very important is the so-called 'best practice frontier' (BPF). The concept of a BPF is used by Silverberg/ Verspagen [2005, 2007] and Goldschlag [2013] to describe the highest possible cell in a row that is known and used, i.e. that is in state 2. The best practice frontier is the technological frontier of all technological niches, i.e. the BPF represents the fittest technology in every niche that is known and used. So, the BPF at time t with N_c is defined as:

$$BPF(t) = \{(i, j(i)), i = 1, ..., N_c\} \text{ with } j(i) = (\max\ j \mid s_{ij} = 2), \qquad (3.1.1)$$

where s_{ij} reflects the state of the cell, i.e. $s_{ij} = 2$ indicates that the technology in the cell is known and used.

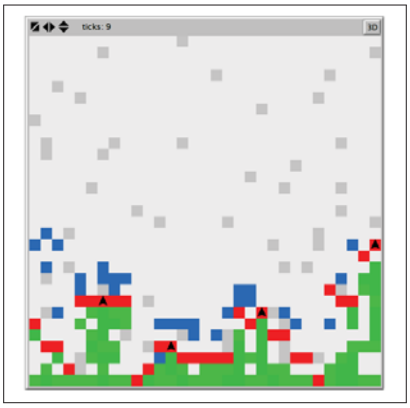


Figure 1: The best practice frontier (BPF) in the basic percolation model. Grey cells are undiscovered (state 0), blue cells are discovered, but not yet used (state 1) and green cells are discovered and viable (state 2). The line of red cells represents the BPF, i.e. red cells are the highest cells in one column that are discovered and viable. Own figure.

As already explained earlier in that paper, to adequately model innovation processes one has to refrain from using neoclassical over-simplifying assumptions, but to build on patterns and stylized facts of the innovation process. The model presented in this paper uses four stylized facts of innovation processes as assumptions/ input factors. First, innovations and technical change are cumulative [Silverberg/ Verspagen, 2005, p. 227], i.e. new knowledge and new technologies always build on previous search activities and discoveries, not only in the same, but also in seemingly unrelated fields. Therefore, in the model an innovation is only generated if an agent connects new knowledge and new technology to its baseline by an unbroken chain of discovered and viable technologies. This means that new technologies in isolation are not innovations, but inventions. Only if agents connect their inventions to previous innovations, they can make economic use of the new technology. Second, innovation processes are uncertain, the arrival of innovations appears to be a stochastic process [Silverberg/ Verspagen, 2005, 2007], i.e. we can't predict innovations in advance, but have to deal not only with risk, but with true uncertainty. Therefore, agents' investment in R&D in the model is related to a random variable $\beta \in [0, 1)$ that is different for every agent in each period, which reflects the stochastic nature of innovation processes. So, in some cases it can be that agents invest in R&D and do not generate inventions or innovations at all. Third, search for new knowledge and new technologies is local [Silverberg/ Verspagen, 2005, p. 227], i.e. agents tend to perform R&D close to technological regions they already know. This is incorporated into the model by a search radius r_s[3] in which the agent searches for new knowledge and performs R&D. Even though it would be possible for the agent to perform R&D in a completely unrelated field outside the agents' search radius, the agent will never do so. Fourth, technical change takes place in relatively ordered pathways [Silverberg/

[3]The search radius r_s used in this model is a Von Neumann or a diamond shaped radius. The radius might have an influence on the way in which agents move through the technology space, such that the paths agents choose with a diamond shaped radius is slightly different from the paths agents would have chosen with a Moore or square shaped radius. Whether this makes relevant difference in the outcome of the model is subject to further research. The radius used in the model can be transformed easily into a square shaped radius.

Verspagen, 2005, p. 227], i.e. "from all the possible directions technological development may take, only a small portion are realized" [Silverberg/ Verspagen, 2005, p. 227]. This is incorporated into to model by agents that can and will use other agents' paths, which leads to technological regions that stay completely undiscovered. By building on these stylized facts, the model is able to replicate empirical facts as the highly skewed size distribution of innovations [Silverberg/ Verspagen, 2005, p. 228], the path-dependency of technical change and innovations [Goldschlag, 2013, p. 2/ 3] and the fact that the arrival rate of innovations tends to cluster in time

3.2 The Firm-Based R&D-Process

Agents in the model actually represent different firms. As the model build in this paper is a simple basic model, it does not incorporate different actors as firms, universities or research organizations, which, however, would be possible. Therefore, when analyzing the results of the model it has to be kept in mind that this version of the model only investigates the behavior of a set of firms. These firms follow simple behavioral rules to move through the technology space and to perform R&D. Before the first model run, firms are randomly distributed on the baseline of the technology space. Each period in time t, firms undergo the following three-step-procedure:

1. Firms scan the best practice frontier BPF, face the highest cell within their search radius r_s that is discovered and viable and move stepwise to that cell.

2. Starting from the BPF, firms randomly choose an undiscovered cell within their search radius r_s and perform R&D on that cell.

3. After the firms have performed R&D, they are rewarded by a certain amount dependent on the size of the innovation they generated.

The first step, the movement to the BPF prior to choosing a cell on which to perform R&D, implies that there are "inter-firm externalities or spillovers, where an active firm can take advantage of innovations made by other firms" [Goldschlag, 2013, p. 5]. So, as another firm already explored the technology, firms do not have to invest in that technology, but can simply add this technology to their technology stock. To which cell in the BPF a firm moves is dependent on the search radius r_s and on coincidence. The higher the search radius, the higher the amount of possible cells on the BPF a firm can move to. A higher search radius enables firms to move to technological niches that are far away from their original technological niche. From the set of all BPF cells in the firm's search radius, the firm randomly chooses the/ one of the highest BPF cells within its search radius. Firms do not simply 'jump' to the BPF, but it is assumed that even though firms can use paths of other firms, moving to the BPF takes time. So firms face the BPF and move to the highest BPF cell, one step each period. This leads to a situation in which firms can use the technology and the technological paths of other firms, however 'learning' and integrating this knowledge takes time and there will be technological leaders and technological followers. This has an influence on the reward firms get for successful innovations, which is explained later.

In the second step, after the firm has moved to the BPF, it locally searches for a cell on which to perform R&D. To do so, the firm randomly selects a cell within its search radius and performs R&D on that cell (reduces the cells resistance value). The fact that firms do not explicitly choose a certain cell, but randomly choose a cell on which to perform R&D, incorporates that research is uncertain and that firms never know in advance in which niche their research is located. The objective of the firm is to reduce the cells resistance value in period t until it becomes zero and the cell switches from undiscovered (0) to discovered but unused (1) or even to discovered and used (2). The cells resistance value ρ_{ij} is reduced by firms' R&D effort according to the following rule:

$$\rho_{\mathrm{ij,t+1}} = \rho_{\mathrm{ij,t}} - b_{\mathrm{t}}\beta \text{ with } \beta \in [0,1), \tag{3.2.1}$$

where b_{t} is the part of the firm's R&D budget that the firm invested in period t to acquire the technology in the cell and β reflects a random variable drawn from a uniform distribution $\beta \in [0,1)$ to reflect the stochastic nature of the R&D process[4]. Dependent on the actual value of β, the 'effective' investment of the firm can be lower than the amount actually invested and therefore can be lower than the resistance value. This can lead to a situation in which the firm invests its whole budget, but does not manage to reduce the cells resistance value at all. However, as all firms follow the same behavioral rules, it is likely that there is more than one firm performing R&D on the same cell. As these firms do not 'cooperate' in the narrow sense of the word, all firms independently invest in the reduction of the resistance value until one firm finally reduces the resistance value to 0. However, as soon as the cell switches to state 1, all firms can use the knowledge without additional effort.

In the third step, the firm is rewarded for the innovation it possibly created and the firm's R&D budget for next period's investment changes. In the model we have both inventions and innovations. An invention happens when a certain cell is set from state 0 to state 1, i.e. a certain technology is discovered due to R&D activities. An innovation happens when the BPF jumps upwards, i.e. when the fittest technologies that are viable and used become even fitter [Silverberg/ Verspagen, 2007, p. 215]. The size of the innovation s_{i} captures the number of rows the BPF has jumped upwards in a certain column in one period [Silverberg/ Verspagen, 2007, p. 215/ 216][5]. Firms in the model are not only rewarded for successful R&D activities, but at the same time they have to bear the costs of their R&D activities. So, the firm's R&D budget in period t consists of an exogenous part, of the budget that is left over from the last period, of the potential reward for successful innovations minus the costs of last period's investment:

$$B_{\mathrm{t}} = \pi_{\mathrm{t}} + B_{\mathrm{t\text{-}1}} + s_{\mathrm{i,\,t\text{-}1}}\pi - b_{\mathrm{t\text{-}1}} \text{ with } B_0 = \pi_{\mathrm{start}} + \pi_0. \tag{3.2.2}$$

π_{t} represents an exogenous part of the firm's budget that every firm gets in each period, which can be seen as a kind of venture capital. π_{start} represents a starting budget that every firm gets in period 0. $B_{\mathrm{t\text{-}1}} + s_{\mathrm{i,\,t\text{-}1}}\pi$ represents the endogenous part of the firm's budget, which consists of the budget that is left over from last period $B_{\mathrm{t\text{-}1}} \in [0,\infty)$, if any, and the reward for a successful innovation generated in column (i) $s_{\mathrm{i,\,t\text{-}1}}\pi$, if any. The budget that is left over from last period $B_{\mathrm{t\text{-}1}}$ can't become negative, i.e. a firm can never spend more than it actually

[4] β varies for every firm in each period of the search process to capture the uncertain nature of innovative search.

[5] In this model, it is assumed that these kinds of innovations reflect incremental innovations as jumps in the BPF show that technologies incrementally become fitter. Whether and how to incorporate different kinds of innovations into the model is open to further research.

has. The reward for an innovation consists of the innovation size $s_{\text{i, t-1}}$ times the payoff per 'unit' of innovation π. The innovation size $s_{\text{i, t-1}}$ captures the number of rows the BPF has jumped upwards in the column the firm had last performed R&D on, no matter if this firm actually 'produced' this innovation. The innovation can also be a product of free-riding from other firms' activities. $b_{\text{t-1}}$ reflects the investment the firm had to make in the last period to perform R&D, i.e. the 'costs' of performing R&D on a cell. The venture capital of each period, the starting budget and the payoff 'per unit' of innovation are assumed to be equal for every firm in each period as uncertainty is already captured by the stochastic parameter. However, to make the model more and more realistic in future research, these parameters can be modified easily to vary for every firm in each period.

In the model, as in the real world, R&D is costly. To reduce a cell's resistance value to 0, a firm has to 'effectively' invest at least ρ_{ij}, i.e. $B_{\text{t}} \overset{!}{>} \rho_{\text{ij,t}} \;\wedge\; b_{\text{t}}\beta \overset{!}{\geq} \rho_{\text{ij,t}}$. As the firm does not know the value of the stochastic parameter, it plans to invest its whole budget and only stops investing if the resistance value is reduced to 0 or if the budget is fully consumed. If the firm's budget (and its 'effective' investment) is sufficient to reduce the resistance value to 0, the cell switches from state 0 to state 1 and it might even be that the firm has some budget left over (if $b_{\text{t}}\beta \geq \rho_{\text{ij,t}} \rightarrow \;\rho_{\text{ij,t+1}} = 0$ and $B_{\text{t+1}} \geq 0$). If the firm's budget is not sufficient to reduce the resistance value to 0, the firm invests its whole budget even though this does not switch the cell from state 0 to state 1 (if $b_{\text{t}}\beta < \rho_{\text{ij,t}} \rightarrow \;\rho_{\text{ij,t+1}} > 0$ and $B_{\text{t+1}} = 0$). As the firm randomly selects a cell on which to perform R&D, it is assumed that the firm will not automatically stay on the cell it previously performed R&D on. If the firm does not manage to successfully perform R&D on a cell in one period, it randomly selects this or another cell in the next period. In the model, this behavior is assumed as firms often perform R&D by trial and error and do never know the exact technological niche they are performing R&D in.

3.3 The Firm-Based R&D-Process in a World with Project Funding

The basic model is extended by subsidized research projects in which firms can participate. Project funding can be turned on and off in the model. The government subsidizes research projects to intervene in market failure. Market failure exists, as firms do not invest the 'socially optimal' amount of money in certain technological fields that are too difficult or too expensive (high resistance value). In these cases, firms tend to work around such technological fields, which is - according to economic theory - a socially undesirable behavior. In a world with project funding, firms are rewarded by a research grant, each period they participate in such a subsidized project. In the model, it is assumed that the firms' search radius for a research project $\text{r}_{\text{s projects}}$ is at least the size of the search radius r_{s} to perform R&D. This is assumed, as the research grant is an extra incentive for the firms to perform R&D in regions they might not have performed without additional financial incentives.

Following the argument of project funding as a policy intervention to correct for market failure, the goal is to subsidize projects in fields in which firms would not invest without additional financial resources. Therefore, in the model the government subsidizes technological fields that are highly complex and therefore too expensive to explore. This means that subsidized research projects are placed on those technological fields that have the highest resistance values. As firms in the model perform R&D according to trial and error and stop to invest in fields in which R&D is not successful, firms are much more likely to choose an easier and less expensive way through the technology space than a way with cells that are highly complex. In the model, there are no certain conditions or restrictions to participate in subsidized projects. All firms with subsidized projects in their radius have the possibility to participate in those projects, no matter how many firms already participate in one project. Firms can participate in a research project until the resistance value of the cell the project is placed on, reaches 0. When the cell switches from state 0 to state 1, project funding is not necessary any more and project funding stops on this cell. This is done to reflect government's behavior just in the moment one project is successfully completed. When one project is successfully completed, another project is placed on the cell in the technology space with the highest resistance value that is not subsidized, yet.

In a world that offers the opportunity to participate in subsidized research projects, the simple behavioral rules of firms are slightly different from those in the basic model. Each period in time t, firms undergo the following three-step-procedure:

1. As in the model without projects, firms scan the best practice frontier BPF, face the highest cell within their search radius r_{s} that is discovered and viable and move stepwise to that cell.

2. In contrast to the model without projects, firms always prefer to perform R&D on a cell that is subsidized by a project. If there exists a subsidized project in the firm's search radius for a research project $\text{r}_{\text{s projects}}$, the firm will move to that project. If there is more than one project, the firm randomly selects one of these projects. If there is no such project, firms will randomly choose an undiscovered cell within their search radius r_{s} (and act as in a world without project funding).

3. After the firms have performed R&D, they are rewarded. Firms that were unable to participate in subsidized projects are rewarded as in a world without project funding. Firms that were able to participate in subsidized projects are also rewarded for innovations they possibly created, but get an additional research grant γ_{t}, no matter if they actually produced an innovation, or not.

The first step, the movement to the BPF prior to choosing a cell on which to perform R&D, is not different from the model without projects.

The second step, however, is. In a model with project funding, firms will always prefer to participate in projects, i.e. they will always prefer to perform R&D on cells that are subsidized by research projects even though these cells are more expensive. This preference changes the firms' way through the technology space. Again, as without project funding, it is likely that more than one firm participates in a research project. In the case with projects, it is even more likely, as $r_{\text{s projects}} \geq r_{\text{s}}$ and as firms will always participate in projects if there are some. In the model it is assumed that all firms that participate in such a research project get the same grant of the same size for each period they participate in such a project.

In the third step, the firm's budget is also dependent on firm's participation in subsidized projects. If firms participate in projects, they get a grant in each period t they perform R&D on a subsidized cell. So, if there is a subsidized project within the search radius for a research project the firm's R&D budget in period t is:

$$B_{\text{t}} = \pi_{\text{t}} + B_{\text{t-1}} + s_{\text{i, t-1}}\pi - b_{\text{t-1}} + \gamma_{\text{t}} \text{ with } B_0 = \pi_{\text{start}} + \pi_0, \qquad (3.3.1)$$

where γ_t represents the research grant the firm gets each period it participates in a research project. If there are no subsidized projects within the search for projects radius of the firm, the firm's R&D budget in period t is again (4.2.2).

The following section shows how the parameterization of the model can lead to different outcomes.

4 Simulation Results

In this paper, the main focus lies on how different variables of the model influence the effect of project funding on firms' innovative performance. Innovative performance in this model is measured in terms of the maximum height of the best practice frontier (BPF) as well as in the number of innovations produced in a model run. The mean and maximum height of the BPF show how 'fit' the technologies in the model are and how 'far' the firms managed to percolate through the technology space. This shows how far the technologies of this economy are developed. Hence, it is assumed that a parameterization that helps firms to reach a higher maximum BPF is better in terms of innovative performance than another parameterization that leads to a situation in which firms can only reach a lower maximum BPF. The same holds true for the number of innovations. The mean number of innovations counts all innovations, which are measured as BPF jumps, that resulted from R&D activities in the model. Even though many economists and politicians yearn for the exact number of innovations generated in an economy, it has to be kept in mind that the number of innovations presented in this paper is only quantitative and gives no qualitative information. The model, as it is now, is not able to differentiate between incremental and radical innovations, nor is it able to make statements about the relevance of single innovations and their impact on the economy.

Besides the maximum BPF and the number of innovations, another outcome that is evaluated is the so-called 'mean trajectory change' of firms. The mean trajectory change measures how often firms change their technological niche in which they perform R&D. This gives information about how diversified research of the firms in the model is. In addition, the mean trajectory changes allow to investigate if and how it is possible to motivate firms to not only stay in their own technological niche. A high or low number of mean trajectory changes of firms can be both positive and negative. On the one hand, firms that work in different fields have access to different kinds of knowledge and can possibly create different, if not breakthrough innovations. On the other hand, it is conceivable that firms that change their technological niche too often do not manage to develop their technologies at all and will therefore stay behind other firms that are more 'focused' (technological leaders). Whether the mean trajectory changes influence firm's innovative performance in a positive or in a negative way is open to further research. However, a world that is increasingly interconnected and complex requires firms that are able to integrate knowledge from different technological fields. These firms have a higher mean trajectory change.

It is often the case that researchers investigate those parameters and parameter changes that can be manipulated by firms or policy makers. Even though it is interesting how, e.g. the payoff per innovation, affects the number of innovations, this is not investigated in the model. The parameters that actually are investigated in the model, are those parameters that can be directly affected by firms or by policy intervention. Therefore, the following effects are analyzed in this chapter: In the sensitivity analysis (4.2), the effects of different model parameters on the innovative performance of firms in terms of the maximum BPF and on the number of projects are investigated. In the further analysis (4.3), the effects of different model parameters on the mean trajectory changes of firms are analyzed. Table 1 summarizes the four tests[6] that are used to investigate the effects of project funding[7].

Test	Definition
Test 1:	Effect of technology space complexity on max BPF and number of innovations.
Test 2:	Effect of number of projects on max BPF and number of innovations.
Test 3:	Effect of technology space complexity on mean trajectory change.
Test 4:	Effect of number of projects on mean trajectory change.

Table 1: Different tests used to investigate the effect of project funding on innovative performance and on mean trajectory changes. Own table.

Before the model results are presented, the next subchapter gives an insight in the parameterization and in the reasons behind the parameterization of the model.

4.1 Parameterization of the Model

Before the first model run, the environment of the model is initialized. Dependent on the parameters chosen by the researcher, the technology spaces and the model outcomes can differ remarkably. The parameters chosen in this analysis try to be in line with real-world parameters to represent reality as good as possible.

In the model it is assumed that we have less firms than technological niches. Dependent on the parameterization, the firms' search radius r_{s} lies between 2 and 5, with a search radius for projects $r_{\mathrm{s\ projects}} = 5$. It is assumed that the search radius for projects is at least of the same size as the 'standard' search radius, as firms are assumed to have a higher willingness to perform R&D in fields that are less related to their own technological niche, if they are rewarded for this behavior. In addition, especially universities and research institutions rely on publicly funded projects. Therefore, they are assumed to be more flexible and to be more likely to work in fields that are less related to their original technological niche. All firms in the model are equipped with a starting R&D budget $\pi_{\mathrm{start}} = 30$, such that all firms have enough money to successfully perform R&D in the first period. Each period t, firms get venture capital π_{t} between 1 and 25. Venture capital of 1 is about 3% of firms payoff per innovations and shall ensure that firms that are unsuccessful in previous periods do not have to leave the market. Venture capital of 5 or 10 is about 15 - 30% of firms payoff per innovations and venture capital of 25 is more than 70% of firms payoff per innovation. Comparing R&D spending as a percentage of revenue in Europe in different industries in 2011, we have spending of less than 3% in chemicals and energy, spendings of 15% in the health sector and spendings of more than 15% in the software or ICT sector [PwC, 2014]. Firms in the model only earn money by creating innovations and spend their whole budget

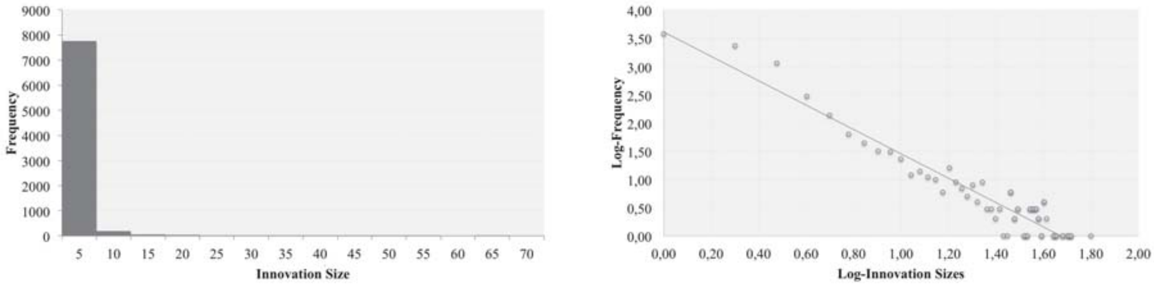
[6]The β-coefficients of the tests result from a simple OLS-Regression. The test statistics can be seen in appendix - D1 - D3.

[7]For a more detailed table of all tests see appendix - B1 & B2.

to perform R&D. Therefore, in the model it is assumed that firms get (what is in the model called) 'venture capital' of the same size as the size of typical R&D spending. Firms that participate in subsidized research projects additionally get research grants γ_t of 10 to 25. These parameters are chosen as the German Federal Government covers up to 50 percent of the project costs of subsidized research projects [Aschhoff, 2009, p. 1]. Research grants of 25 are chosen to investigate the impact of research grants that are remarkably higher than those usually paid. Even though, in absolute terms, the number of subsidized research projects is higher than the number of firms in the model, the number of subsidized projects that are accessible in one period is lower. So in the model, there a fewer subsidized research projects that are accessible in single periods than firms. After the model is initialized using the parameterization explained above, the model runs a fixed number of periods such that different outcomes can be analyzed. All model outcomes presented in this paper (except for the typical model run presented in this section) are resulting from ten model repetitions with 100 periods, each model run.

Before the evaluation of the model outcomes (the sensitivity analysis), the model has to be verified and validated. This means that it has to be ensured that the researcher has built the model right (verification) and that the researcher has built the right model (validation) [Balci, 1997, p. 135]. One possibility to assess the validity of the simulation model is the so-called empirical validation, to evaluate the "extent to which the model's outputs approximate reality, typically described by one or more 'stylized facts' drawn from empirical research" [Fagiolo et al., 2007, p. 191]. As the model of Silverberg/ Verspagen [2005, 2007] and Goldschlag [2013], the model presented in this paper is able to replicate stylized fact of innovation processes, namely the highly screwed distribution of innovation sizes and the roughly linear decrease in the frequency of innovation sizes, suggesting a power-law process. Figure 2 shows the stylized facts resulting from a typical model run[8]. On the left-hand side (figure 2(a)), the histogram demonstrates the highly skewed size distribution of innovation sizes in the model, with many small innovations and only very few larger innovations. On the right-hand side (figure 2(b)), the log-log-plot demonstrates the roughly linear decrease in innovation size frequency. Simple OLS-regression gives a β-coefficient of -2,16 (with $R = 0,93, R^2 = 0,92$ and $p < 0,01$). These results indicate that the model is able to replicate empirical facts.

[8]See appendix - A for the parameters of a typical model run.



(a) Histogram of innovation sizes.

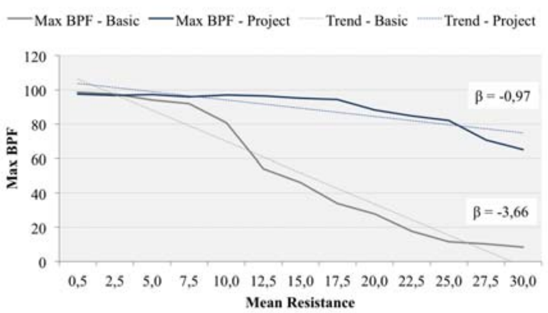
(b) Log-log graph of innovation sizes.

Figure 2: Stylized facts in the model. Own figure.

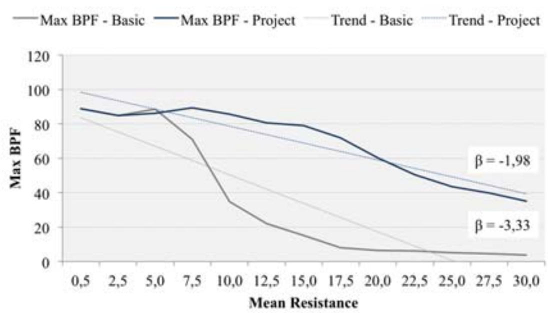
4.2 Sensitivity Analysis

The sensitivity analysis investigates the effects of changes in model parameters on model outcomes. The following subchapter presents the model results of parameter changes on innovative performance. Test 1 investigates how the effect of an increase in technology space complexity on firms' innovative performance is affected by different search radii (test 1a), by different financial resources (test 1b) and by different financial resources, but equal research grants (test 1c). The test compares the results of firms in a world with project funding to the results of firms in a world without project funding. Test 2 analyzes how the effect of an increase in the number of subsidized projects on firms' innovative performance is influenced by different search radii (test 2a), by different financial resources (test 2b) and by different financial resources, but equal research grants (test 2c). This tests investigates these effects only in a world with project funding.

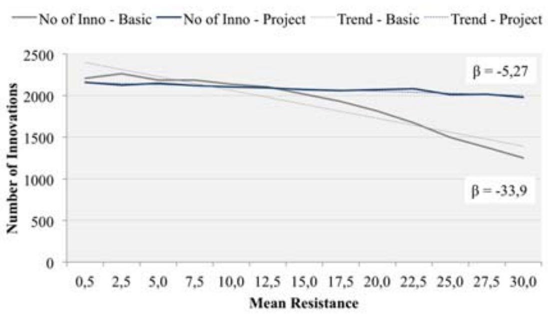
Test 1a investigates how the maximum best practice frontier and the number of innovations change with increasing complexity of the technology space and with different search radii. This is done to analyze whether the fact that search is local has an effect on firms' innovative performance and whether this effect is different in technology spaces that differ in their complexity. In the model of Silverberg/ Verspagen [2005], an increasing search radius leads to a situation in which "the mean rate of innovation increases until a plateau is reached" [Silverberg/ Verspagen, 2005, p. 225]. Figure 3 compares a situation when firms have a low search radius (figure 3(a) and 3(c)) to a situation when firms have a high search radius (figure 3(b) and 3(d)). First, it can be seen that the maximum BPF that is reached with and without project funding decreases the more complex the technology space gets. In addition, firms in a world with project funding outperform firms in a world without project funding, especially with increasing technology space complexity. In a world with project funding, the negative relationship between the maximum BPF and the mean resistance value is stronger with a higher search radius. In a world without project funding, the strong decrease in innovative performance already occurs in simpler technology spaces if firms have a higher search radius. Figure 3(c) and 3(d) show that an increase in technology space complexity leads to a decrease in the number of innovations produced in an economy. The negative effect of technology space complexity on innovative performance is six times stronger in a world without project funding than in a world with project funding. Even though this negative effect is of almost the same size with high and low search radius, the total number of innovations with high search radius is only of about 70% of the number of innovations with a lower search radius. Different from the maximum BPF, the number of innovations in a world with project funding is not always higher than the number of innovations in a world without project funding. With low search radius, the number of innovations in a world with project funding is only higher than the number of innovations in a world without project funding, after the technology space reached a certain complexity threshold. With low search radius in a simpler technology space, the number of innovations without projects is even higher than the number of innovations with projects. Figure 3 shows that, in contrast to the results of Silverberg/ Verspagen [2005], the effect of a higher search radius on innovative performance is negative and that firms with a lower search radius perform better than firms with a higher search radius, even in more complex technology spaces.



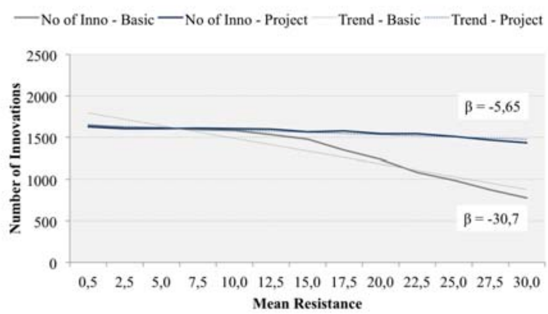
(a) The max best practice frontier (BPF) dependent on technology space complexity with low search radius.



(b) The max best practice frontier (BPF) dependent on technology space complexity with high search radius.



(c) Number of innovations dependent on technology space complexity with low search radius.

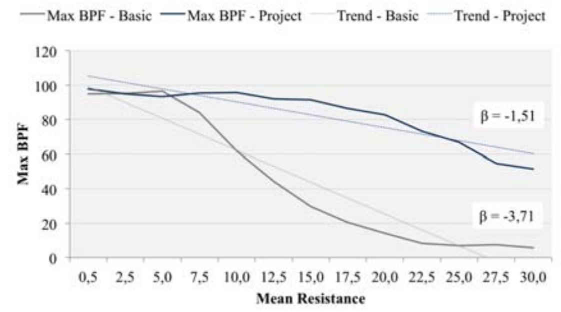


(d) Number of innovations dependent on technology space complexity with high search radius.

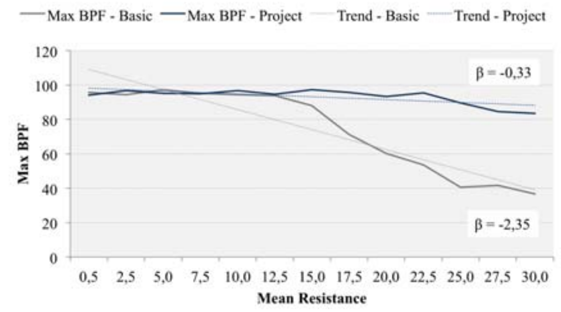
Figure 3: Test 1a: The best practice frontier (BPF) and the number of innovations dependent on technology space complexity and search radius. Own figure.

Test 1b investigates how the maximum best practice frontier and the number of innovations change with increasing complexity of the technology space in a situation with and without venture capital. This is done to investigate whether firms that have access to venture capital perform significantly better than firms that have no access to venture capital and to investigate which role technology space complexity plays in both situations[9]. Figure 4 compares a situation in which firms have no venture capital (figure 4(a) and 4(c)) to a situation in which firms have venture capital (figure 4(b) and 4(d)). As in test 1a, the maximum BPF decreases with increasing technology space complexity in both situations. It can be seen that the maximum BPF that is reached in a world with project funding is higher than the maximum BPF that is reached in a world without project funding. In addition, the negative effect of increasing technology space complexity is stronger in situations in which firms have no venture capital. The gap between firms with and without project funding increases with increasing technology space complexity. However, if firms get venture capital, the difference between the maximum BPF reached in a world with and without project funding only exists for more complex technology spaces. Also, it seems as if the decrease in the maximum BPF in more complex technology spaces is smaller, if firms get venture capital. Besides the complexity of the technology space, the amount of venture capital seems to have an important impact on the maximum BPF that can be reached by the firms. Figure 4(c) and 4(d) show that the number of innovations decreases with increasing technology space complexity, with a stronger decrease in a world without project funding. In simpler technology spaces, firms without project funding perform as good as firms with project funding. The more complex the technology space gets, the greater becomes the gap between firms in a world with project funding and firms in a world without project funding. With venture capital, the number of innovations is not as affected by increasing technology space complexity as without venture capital. The number of innovations of firms in a world with project funding with venture capital almost seems stable, unaffected by increasing technology space complexity. This shows again that additional financial resources as venture capital seem to have an important impact on the number of innovations that can be generated by the firms. Figure 4 shows that firms in a world without project funding that have access to venture capital still perform worse than firms in a world with project funding, however the gap in performance is smaller if firms get venture capital.

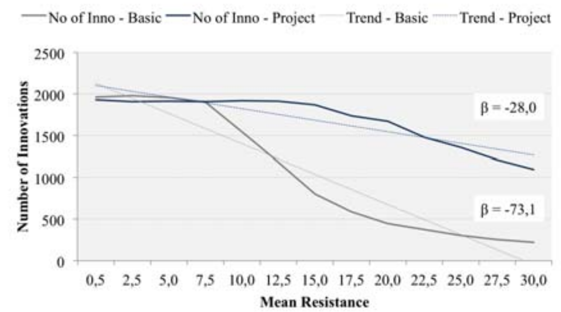
[9] In this test, firms 'without' venture capital actually get a negligible amount of capital that ensures that these firms are not driven out of the market, even though they do not get enough venture capital to successfully perform R&D.



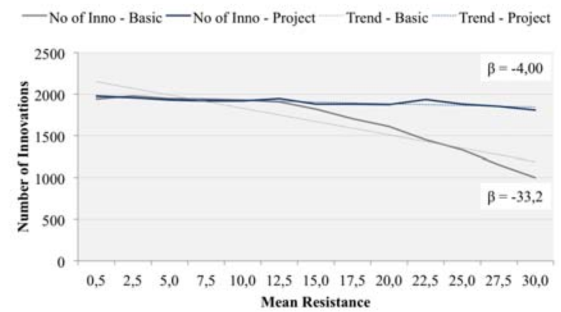
(a) The max best practice frontier (BPF) dependent on technology space complexity without venture capital.



(b) The max best practice frontier (BPF) dependent on technology space complexity with venture capital.



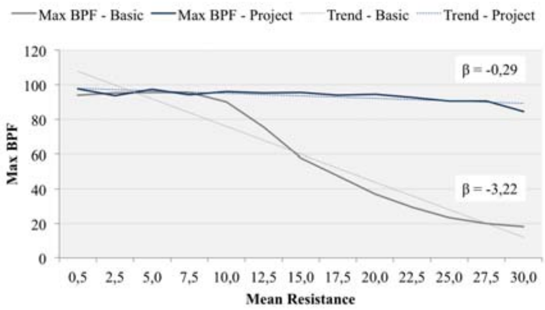
(c) Number of innovations dependent on technology space complexity without venture capital.



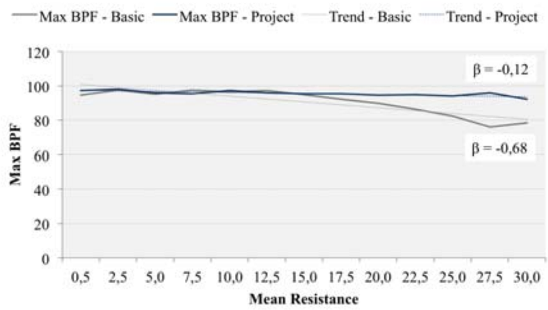
(d) Number of innovations dependent on technology space complexity with venture capital.

Figure 4: Test 1b: The best practice frontier (BPF) and the number of innovations dependent on technology space complexity and venture capital. Own figure.

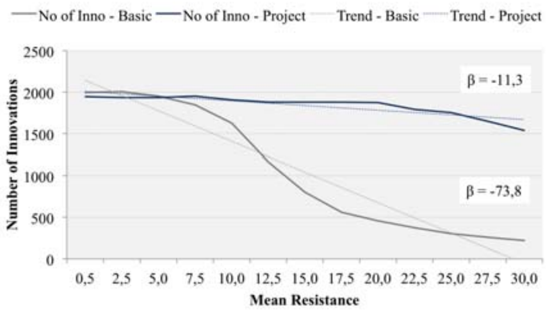
Test 1c explores how the maximum best practice frontier and the number of innovations change with increasing complexity of the technology space and with different amounts of venture capital, but high research grants in both situations. Of course, only firms in a world with project funding that actually participate in projects get these high research grants. Test 1c is carried out as test 1b showed that the gap in performance between firms in a world with and without project funding is smaller, if firms get venture capital. Therefore, this test aims at investigating whether firms in a world without subsidized research projects can perform as good as subsidized firms, if they have enough capital. Figure 5 compares the performance of firms that have low venture capital, but high research grants (figure 5(a) and 5(c)) to the performance of firms that have high venture capital and high research grants (figure 5(b) and 5(d)). The figure shows that, even though statistically significant at a 5% level, the effect of technology space complexity on the maximum BPF in a world with project funding is very small, if not negligible. So, the higher the financial resources of the firm, the lower the effect of the resistance value on the BPF. In simple technology spaces, the maximum BPF is the same for firms with and without project funding and the maximum BPF is not decreasing with increasing technology space complexity. With low venture capital, the more complex the technology space gets, the worse firms without project funding perform compared to firms with project funding. Firms in a world without project funding that receive high venture capital perform almost as good as firms in a world with project funding that receive both high venture capital and high grants, even if the technology space becomes increasingly complex. This suggests that firms without project funding can perform as good as firms with project funding if they get enough capital. Comparing the results of test 1b to the results of test 1c shows that this effect gets more pronounced, the higher the capital of all firms is. Figure 5(c) and 5(d) show that the results for the number of innovations are relatively similar to the results for the maximum BPF. Again, in a simple technology space there is almost no difference in the performance of the firms. The more complex the technology space gets, the greater becomes the difference in the number of innovations in a world with and without project funding. This difference, however, decreases with higher venture capital, but not as pronounced as the gap between the maximum BPFs. Figure 5 shows that higher financial resources can decrease the gap in performance between firms in a world with and without project funding. This indicates that higher financial resources can offset the effect of project funding.



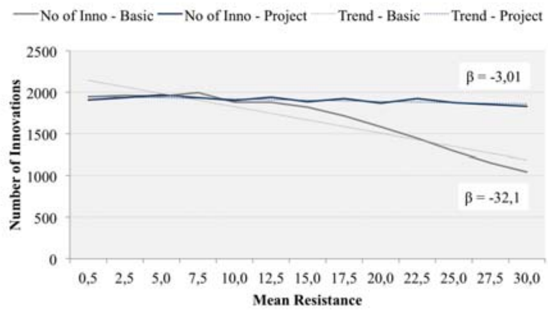
(a) The max best practice frontier (BPF) dependent on technology space complexity with low venture capital and high research grants.



(b) The max best practice frontier (BPF) dependent on technology space complexity with high venture capital and high research grants.



(c) Number of innovations dependent on technology space complexity with low venture capital and high research grants.

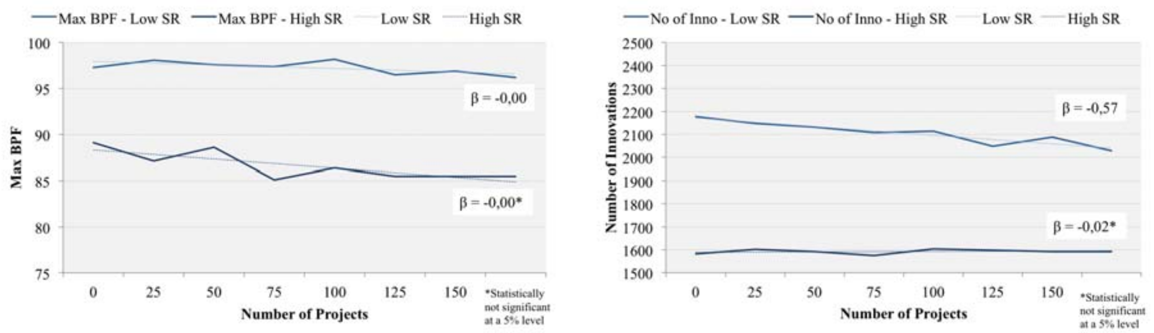


(d) Number of innovations dependent on technology space complexity with high venture capital and high research grants.

Figure 5: Test 1c: The best practice frontier (BPF) and the number of innovations dependent on technology space complexity and venture capital and research grants. Own figure.

While Test 1 investigates different outcomes of the model and their difference between model runs with and without project funding, test 2 investigates different outcomes of the model exclusively in a world with project funding.

Test 2a investigates how the maximum best practice frontier (figure 6(a)) and the number of innovations (figure 6(b)) change with increasing number of subsidized research projects and with different search radii. This is done to explore whether the effect of an increasing number of subsidized research projects on the maximum BPF and on the number of innovations is different with different search radii. In figure 6, it can be seen that the number of subsidized projects has no significant effect on the maximum BPF, neither for high nor for low search radii (figure 6(a)). There is also no significant or only a very small effect of the number of projects on the number of innovations (figure 6(b)). Even though one might have expected an increasing performance with an increasing number of subsidized projects, this appears not to hold true in the model. However, independent of the number of research projects, there is a huge difference in the innovative performance of firms with high and low search radius. Both the maximum BPF and the number of innovations are higher for firms with a lower search radius than for firms with a higher search radius. This result is in line with the results of test 1a, i.e. firms with lower search radius perform better than firms with higher search radius, independent of the number of subsidized projects. Following the results of this test, it would be more profitable for the government to influence firms' search radius than to increase the number of subsidized projects.

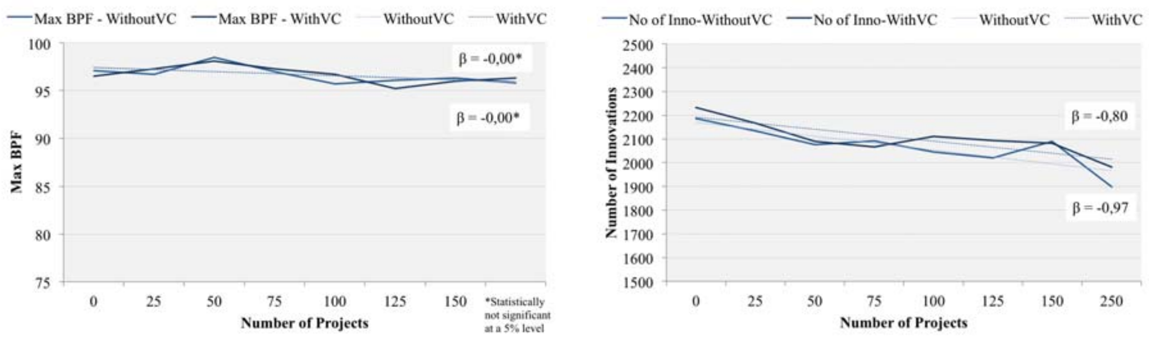


(a) The max best practice frontier (BPF) dependent on number of subsidized projects and search radius.

(b) The number of innovations dependent on number of subsidized projects and search radius.

Figure 6: Test 2a: The best practice frontier (BPF) and the number of innovations dependent on the number of subsidized projects and search radius. Own figure.

Test 2b investigates how the maximum best practice frontier (figure 7(a)) and the number of innovations (figure 7(b)) change with increasing number of subsidized research projects in a situation with and without venture capital. This helps make statements about whether an increasing number of subsidized projects affects innovative performance differently, if firms have different financial resources. Figure 7 shows that the number of subsidized projects has no significant effect on the maximum BPF reached by firms in the model, neither without nor with some venture capital. Concerning the number of innovations in the model, the number of projects has a small, but still significant negative effect on the innovations generated by firms. The number of innovations decreases with increasing number of projects for both situations with and without venture capital. This is an interesting result as subsidized research projects are supposed to stimulate and not hinder innovations. Surprisingly, the number of subsidized projects in the model has no or only a small negative effect on innovative performance.

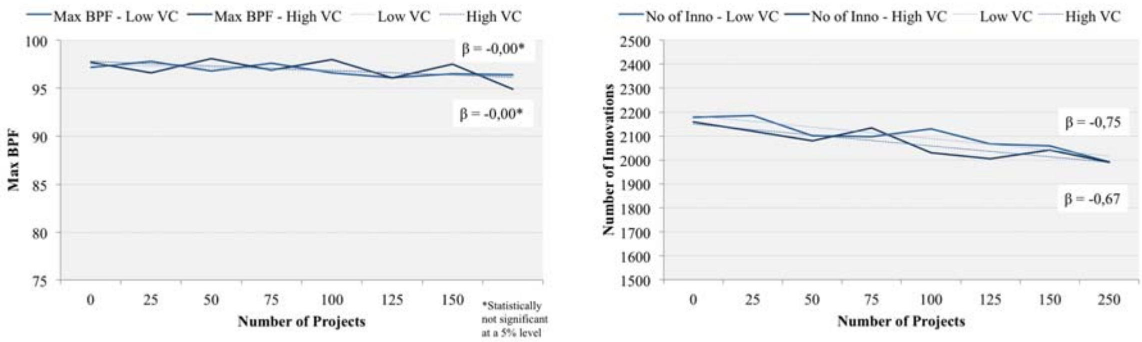


(a) The max best practice frontier (BPF) dependent on number of subsidized projects and venture capital.

(b) The number of innovations dependent on number of subsidized projects and venture capital.

Figure 7: Test 2b: The best practice frontier (BPF) and the number of innovations dependent on the number of subsidized projects and venture capital. Own figure.

Test 2c investigates how the maximum best practice frontier (figure 8(a)) and the number of innovations (figure 8(b)) change with increasing number of subsidized research projects and with different amounts of venture capital (but high research grants). This is done to investigate whether the effect of subsidized projects can also be achieved for firms without project funding by increasing their venture capital. Figure 8 shows that, as already shown by test 2b before, there is no difference in the height of the maximum BPF of firms with different amounts of venture capital. Even though test 1c showed that venture capital can compensate for project funding, this appears to only hold true for the difference between firms with and without project funding. Comparing firms in worlds in which both have access to project funding, there is no big difference in performance due to a difference in venture capital. Again, the effect of the number of projects is only very small, but significantly negative, independent of firms' venture capital.



(a) The max best practice frontier (BPF) dependent on number of subsidized projects and venture capital and research grants.

(b) The number of innovations dependent on number of subsidized projects and venture capital and research grants.

Figure 8: Test 2c: The best practice frontier (BPF) and the number of innovations dependent on the number of subsidized projects and venture capital and research grants. Own figure.

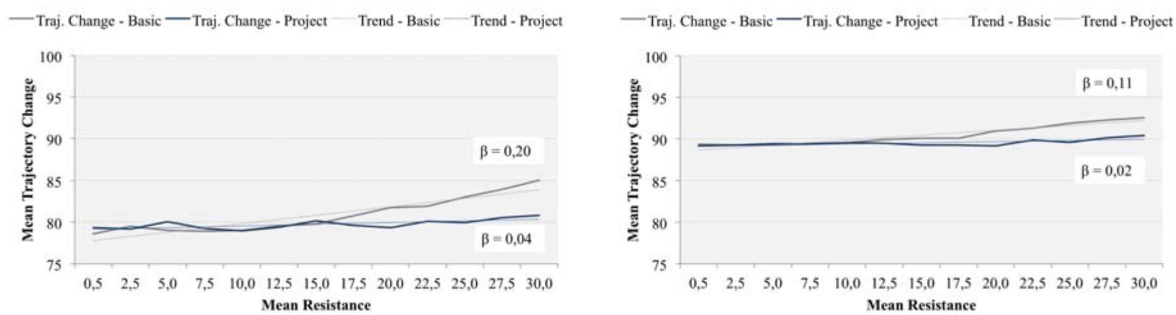
Summing up, test 1 and 2 lead to some important results. First, firms' performances decrease with increasing technology space complexity. Second, firms in a world with project funding perform better than firms in a world without project funding. Third, the number of subsidized research projects does not affect firms' innovative performance in terms of the maximum BPF, the only effect that can be seen is a small decrease in the number of innovations if the number of subsidized projects increases. Fourth, it appears as if the decrease in performance resulting from an increase in technology space complexity can be offset by an increase in venture capital. The same holds true for the worse performance of firms that are not participating in subsidized research projects. Fifth, independent of technology space complexity and the number of subsidized research projects, a higher search radius leads to a poorer performance for both worlds with and without project funding.

4.3 Further Analysis

While test 1 and test 2 are analyzing innovative performance in the narrow sense of the word, test 3 and test 4 do not analyze the effect of parameter changes on innovative performance, but they analyze the effect of parameter changes on mean trajectory changes. Therefore, in this paper these tests are not included in the sensitivity analysis, but in a further analysis. Test 3 investigates how the effect of an increase in technology space complexity on firms' mean trajectory changes is affected by different search radii (test 3a), by different financial resources (test 3b) and by different financial resources, but equal research grants (test 3c). The test compares the results of firms in a world with project funding to the results of firms in a world without project funding. Test 4 analyzes how the effect of an increase in the number of subsidized projects on firms' mean trajectory changes is influenced by different search radii (test 4a), by different financial resources (test 4b) and by different financial resources, but equal research grants (test 4c). The tests investigates these effects only in a world with project funding.

Mean trajectory changes measure how often firms move between different technological niches or fields to perform R&D. This is an important measure as the trajectory change gives information about whether project funding helps make firms move between different technological fields which can lead to knowledge spillovers in other industries by creating chain-links. Firms that perform R&D in different technological niches with different partners from other technological fields are more likely to combine different kinds of knowledge and possibly create not only incremental but also radical innovations. But, as already stated above, firms that change their technological niche too often could be outperformed by firms that are more 'focused'. The relationship between innovative performance and trajectory changes and how both interact is an important topic, but, due to limited space, subject to further research. However, by simply comparing the effects of parameter changes on innovative performance and on trajectory changes, it can be seen that the effects are always contradictory.

Test 3a investigates how the mean trajectory change varies with increasing complexity of the technology space and with low search radius (figure 9(a)) and high search radius (figure 9(b)). This is done to investigate whether firms that have a higher search radius change their technological niche more often than firms that have a lower search radius and how this is affected by project participation. Figure 9 shows that the mean trajectory change of firms in a world with project funding is relatively stable, even with increasing technology space complexity. The effect of an increasing technology space complexity on the mean trajectory change of firms in a world with project funding therefore is almost negligible. This result holds true for both high and low search radius. In contrast, the mean trajectory changes of firms in a world without project funding increase with increasing technology space complexity for both high and low search radius, with a higher increase with a lower search radius. However, even though statistically significant, this effect still is very low. For both worlds, with and without project funding, the mean trajectory changes are significantly higher for firms with a higher search radius.

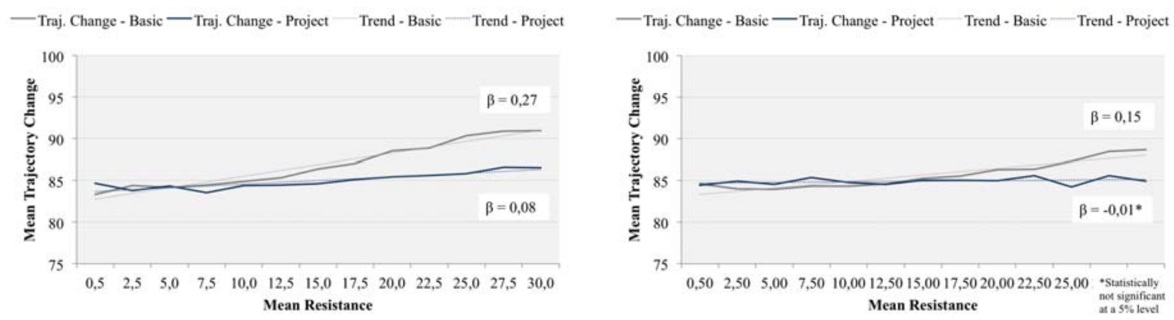


(a) Mean trajectory change of firms dependent on technology space complexity with low search radius.

(b) Mean trajectory change of firms dependent on technology space complexity with high search radius.

Figure 9: Test 3a: Trajectory change dependent on technology space complexity and search radius. Own figure.

Test 3b investigates how the mean trajectory change varies with increasing complexity of the technology space in a situation with venture capital (figure 10(b)) as well as without venture capital (figure 10(a)). This is done to explore whether venture capital has an influence on how often firms change their technological niche. Figure 10 shows that, in contrast to test 3a, the mean trajectory changes are relatively similar for both situations with and without venture capital. Again, the mean trajectory changes of firms in a world with project funding are relatively stable even in complex technology spaces. As before, the mean trajectory changes of firms in a world without project funding increase with increasing technology space complexity, with a higher increase in the situation without venture capital.

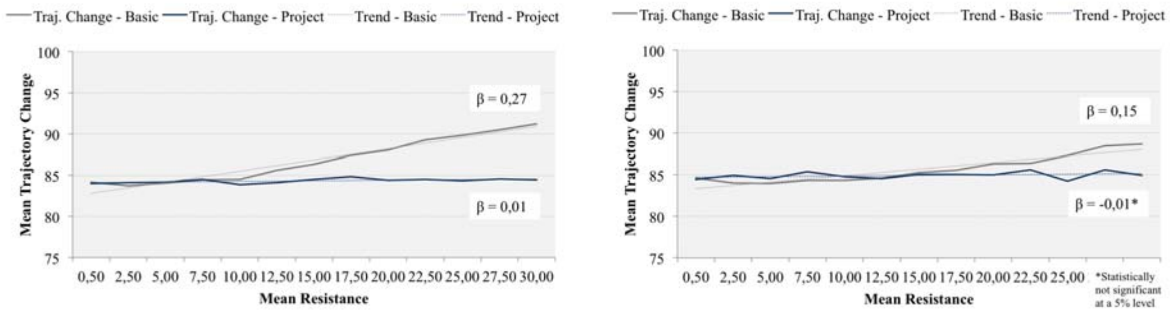


(a) Mean trajectory change of firms dependent on technology space complexity without venture capital.

(b) Mean trajectory change of firms dependent on technology space complexity with venture capital.

Figure 10: Test 3b: Trajectory change dependent on technology space complexity and venture capital. Own figure.

Test 3c investigates how the mean trajectory changes vary with increasing complexity of the technology space and with low venture capital, but high research grants (figure 13(a)) and with high venture capital and high research grants (figure 13(b)). This is done to make statements about whether venture capital can compensate for project funding. Figure 13 shows almost the same results as figure 12, the mean trajectory changes of firms with project funding are not affected by an increase in technology space complexity, neither with high nor with low venture capital. The mean trajectory changes of firms without project funding increase with increasing technology space complexity and the effect in a case with low venture capital is almost two times the size of the effect in a case with high venture capital.

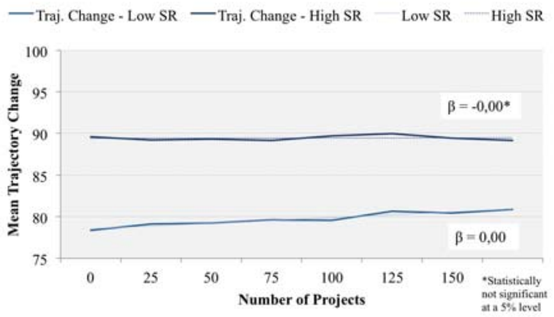


(a) Mean trajectory change of firms dependent on technology space complexity with low venture capital and high research grants.

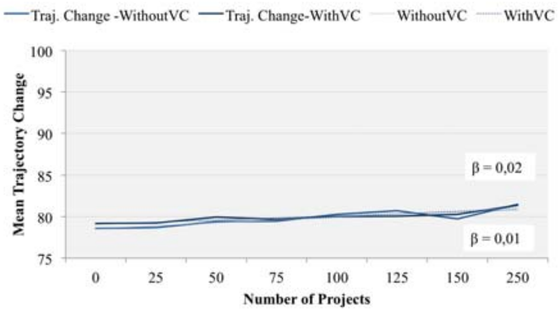
(b) Mean trajectory change of firms dependent on technology space complexity with high venture capital and high research grants.

Figure 11: Test 3c: Trajectory change dependent on technology space complexity and venture capital and research grants. Own figure.

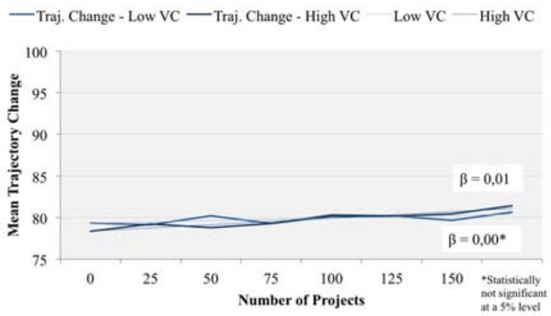
Test 4 investigates how an increasing number of subsidized projects affects firms' mean trajectory changes. The test investigates the impact of the search radius on the effect of project funding (figure 12(a)), the impact of venture capital on the effect of project funding (figure 12(b)) and the impact of venture capital and research grants on the effect of project funding (figure 12(c)). This is done to investigate whether politicians can influence how often firms change their technological niches by increasing the number of subsidized research projects or by influencing one of the other parameters named above. As figure 12 shows, the mean trajectory changes of firms seem to be relatively independent of the number of research projects. The effect of an increase in the number of projects is either statistically not significant or almost zero. In addition, firms' mean trajectory changes do not differ, even though their financial resources differ. The only thing that has a huge influence on firms' mean trajectory changes is the search radius. Firms with a higher search radius change their technological niche more often than firms with a lower search radius.



(a) Test 4a: Mean trajectory change dependent on number of subsidized projects and search radius.



(b) Test 4b: Mean trajectory change dependent on number of subsidized projects and venture capital.



(c) Test 4c: Mean trajectory change dependent on number of subsidized projects and venture capital and research grants.

Figure 12: Test 4: Trajectory change dependent on the number of subsidized projects, on the search radius, on venture capital and on research grants. Own figure.

Summing up, test 3 and 4 show that the mean trajectory changes of firms in a world with project funding are relatively independent of increasing technology space complexity, whereas the mean trajectory changes of firms in a world without project funding show a small increase with increasing technology space complexity. The number of subsidized research projects has only little, if not no influence on how often firms change their technological niche. For both increasing technology space complexity and increasing number of subsidized projects, firms with a higher search radius change their technological niche more often than firms with a lower search radius.

4.4 Discussion

The four tests applied in this paper and presented in the previous two subsections aim at investigating the effects of project funding on firms' innovative performance. Test 1 and 2 lead to three main results.

First, firms' innovative performance decreases with increasing technology space complexity. This result is not surprising at all. The more complex the technology space gets, the more financial resources and the more time firms need to successfully perform R&D. Firms need more financial resources as the cells' resistance values are higher in a more complex technology space. Higher resistance values imply higher 'costs' to switch the cells' state. Firms need more time as they have to stop performing R&D as soon as they have no financial resources left. Firms that already spent all their resources (which can easily happen in a complex technology space) cannot successfully perform R&D until they have waited long enough to get access to other financial resources as, for instance, to venture capital.

Second, firms in a world with project funding outperform firms in a world without project funding. This result becomes even more pronounced as the technology space complexity increases. The second result is easily understood if one understands the reason for the first result. In contrast to firms in a world without project funding, firms in a world with project funding have access to those additional financial resources that allow them to bear higher resistance values or 'costs' in a more complex technology space and they don't have to stop their R&D activities when firms without project funding have. In a world with project funding, even firms that are not participating in subsidized projects benefit from technology or knowledge spillovers, which increases performance of the economy as a whole. This also explains the third result.

Third, if all firms already have the possibility to perform in subsidized projects, a further increase in financial resources by an increase in subsidized projects does not lead to a better performance in terms of the maximum BPF and the number of innovations. This is the case as firms always need at least one period to successfully perform R&D on a technological field. Therefore, more financial resources do not increase firms' performance anymore. If project subsidies are already sufficient, more projects (and therefore more financial resources) cannot help reduce cells' resistance values faster. One could say that even though additional financial resources significantly foster innovative activities, this works only to a certain degree. Knowledge and new technologies still have to be understood and integrated. It even can be that with increasing number of projects the number of innovations decreases. This happens as with too many projects firms start 'project hopping' or 'technology hopping' and stop increasing the fitness of their own technological niche. This means that firms participate in all subsidized projects within their search radius, no matter if these projects subsidize technologies that are less developed than their own technology. In this case, too many subsidized research projects in the firm's radius disturb the technological trajectories the firm would have followed in a world without project funding. In addition, if firms are participating in projects that are far away from their own technology stock, it even can be that these firms cannot connect this knowledge to their technology stock. So, they cannot produce an innovation.

Explaining these three main results helps to guide further research and to make policy recommendations concerning the efficiency and necessity of subsidized research projects. If the results of this model imply that the advantage of subsidized projects exclusively comes through more financial resources, then firms in a world without project funding have to be able to perform as good as firms in a world with project funding, if they have enough financial resources. This is exactly what the model results showed. The decrease in performance (of firms both in a world with and without project funding) resulting from an increase in technology space complexity can be offset by an increase in venture capital. The same holds true for the worse performance of firms that are not participating in subsidized research projects compared to the performance of firms that are participating in subsidized research projects. This shows that, at least in the model world, firms in a complex technology space can perform as good as they can in a simple technology space and they can perform as good without project funding as they can with project funding, if they get enough financial resources. The results indicate that the effect of project funding is simply a financial one. This leads to the question whether other policy instruments as, for instance, institutional funding would lead to the same or even to better results than project funding. Another interesting result shows that a higher search radius leads to a poorer innovative performance (in contradiction to the results of Silverberg/ Verspagen [2005]). This is the case as firms with a higher search radius perform R&D in many different, unrelated fields. These fields are far away from the firms' technology stocks. Therefore, these firms are not able to connect the new knowledge to their knowledge stock and to generate innovations with this knowledge. This is in line with the neo-Schumpeterian idea that knowledge builds on already existing knowledge and cannot be simply 'used' by everyone. If the only observable effect is that project funding increases firms' innovative performance, as it increases firms' financial resources, it has to be questioned if project funding affects other parameters. Test 3 and 4 investigate whether firms' mean trajectory changes could be one of the other parameters affected by project funding.

Test 3 and 4 lead to four main results. To be able to interpret these results, it has to be kept in mind that how often firms change their technological niches depends on the largest part on the search radius, the search for projects radius and whether or not firms actually participate in projects. The higher the search radius, the lower the probability of a single cell to be chosen, but the higher the probability of a firm to change its technological niche. The probability of a firm with search radius $r_s = 1$ to change its technological niche is 40%, the probability of a firm with search radius $r_s = 2$ to change its technological niche is higher than 60% and the probability of a firm with search radius $r_s = 3$ to change its technological niche is higher than 70%. Regarding this explanation, the first three results are not surprising.

First, for both increasing technology space complexity and increasing number of subsidized projects, firms with a higher search radius change their technological niche more often. This can be easily explained. As a higher search radius increases the probability to change the technological niche, firms with a higher search radius change their niche more often.

Second, the mean trajectory changes of firms in a world with project funding are relatively independent of increasing technology space complexity. This is due to the fact that, if firms have enough financial resources, firms' search radius is the decisive factor that is able to influence the mean trajectory changes. If firms have enough capital to percolate goal-directed through the technology space, only the search radius influences firms' mean trajectory changes. There are cases in which firms' search radius is not the only factor able to influence trajectory changes, one of these cases is explained in result 4.

Third, the number of subsidized research projects only has little to no influence on how often firms change their technological niche. As trajectory changes are dependent on the search radius, and as the search radius for projects $r_{s\ projects}$ has at least the size as the 'standard' search radius r_s, firms in a world with subsidized projects theoretically change their technological niche more often, as their probability to change their niche is higher. However, the increase in the number of trajectory changes is only marginal, as there are not enough projects in the model to affect the search radii of all firms. Therefore, the small effect almost appears as if there actually is no effect. The only result that cannot be explained by the search radius is the fourth result.

Fourth, the mean trajectory changes of firms in a world without project funding slightly increase with increasing technology space complexity. This result can be explained by the fact that to successfully change a cell's state firms in more complex technology spaces have to perform R&D on more lattice cells in more periods than they have to do in simpler technology spaces. As firms in complex technology spaces often cannot reduce a cell's resistance value in one period, they have to reduce the resistance value of this or another cell in their search radius in the next periods. To put it simple, the more complex the technology space is, the more difficult it is for the firms to percolate goal-directed through the technology space and the more the firms have to try many different paths. This is in line with the second result. As firms in a world with project funding have higher financial resources, they can percolate more goal-directed through the technology space and they do not need to try many different paths to the left or to the right. Therefore, these firms are not as affected by technology space complexity as firms in a world without project funding.

Summing up, given the architecture of the model and the definition of innovation in the model, the outcomes resulting from test 1, 2, 3 and 4 are not surprising. Following the model results of this simple basic model, the only way government can influence firms' innovative performance is to provide sufficient financial resources (which can be by project funding or other policy instruments) and to influence firms' search radius.

5 Summary and Conclusion

In Germany, the Federal Government spends more than seven billion Euro a year on direct project funding (DPF) to correct for market failure [BMBF, 2014g]. Market failure occurs because knowledge is a 'latent public good' [Nelson, 1989]. The public good features of knowledge lead to positive externalities. Due to these externalities, there exist technological regions or fields in which firms invest less in R&D than the socially optimal amount [Arena et al., 2012, p. 274/275]. As a result, the German Federal Government subsidizes research projects in 'desirable' fields as in the fields of climate and energy, health and nutrition, mobility, security and communication [BMBF, 2014a]. However, project funding costs billions of Euro and in a world that faces shrinking government budgets and international competition "knowing and increasing the efficiency of innovation policies has become crucial" [Aschhoff, 2008, p. i]. This is particularly the case as the effects of project funding can be both positive and negative. Hence, the evaluation of these different effects of project funding is of utmost importance. Therefore, in this paper, the effects of subsidized research projects on firms' innovative performance have been investigated by using an agent-based percolation model.

The model results show that firms in a world with project funding outperform firms in a world without project funding in terms of the maximum BPF and the number of innovations. In addition, the innovative performance of firms in a less complex technology space is significantly higher than the innovative performance of firms in a more complex technology space. Therefore, it is not surprising that the gap in performance between firms in a world with and without project funding increases with increasing technology space complexity. However, this difference in performance can only be observed between firms in a world with and without project funding. If all firms have the possibility to participate in subsidized research projects, there is no difference in the firms' performances, even if the firms differ in the amount of their financial resources. Also an increasing number of subsidized projects has no (positive) effect on firms' innovative performance. One of the most important results of the model is that additional financial resources, e.g. resulting from venture capital, can substitute for project funding. Hence, the positive effects of subsidized projects on innovative performance can also be achieved in a world without project funding if firms have access to other financial resources. This result indicates that, at least in the model, the effect of project funding on innovative performance is a purely financial one.

The model results lead to the following conclusions. The more complex the technology space gets, the more effective and important subsidized research projects are. But, to avoid a waste of resources, the number of subsidized projects has to be regimented. In addition and not surprising, the more financial resources firms already have, the less important subsidized research projects are. Furthermore, at least in the model, policy intervention can even lead to negative results if too many subsidized projects disturb firms' paths through the technology space. Even though the model shows that firms have to be supported by additional financial resources the more complex the technology space gets, these financial resources do not necessarily have to come from project funding. In addition, as project funding only subsidizes certain technological fields for a short period of time, firms participate in a project to get additional financial resources. Subsidized projects do not necessarily influence firms' trajectory changes or firms' long-term path through the technology space. This leads to the question whether project funding can achieve its goal to foster innovations in socially desirable fields. Even though the firms perform R&D on subsidized fields, this does not automatically imply that they create innovations in these fields.

Summing up, subsidized research projects can have both positive and negative effects. As the model shows that the positive effects of project funding can also be achieved with additional capital from other sources (e.g. venture capital, institutional funding), further research is necessary to decide whether or not the benefits of project funding do outweigh its costs. One research question could be whether the effects of direct project funding could also be achieved with institutional funding or other policy instruments or if different forms of funding do even lead to better results than project funding does.

Regarding these results, it has to be kept in mind what kind of model we have and what limitations we face. The most important aspect is that this model represents a simple basic model that was created to show how such an agent-based percolation model can possibly look like. Therefore, this model aims at being an inspiration for creating a more elaborate model. Besides this aspect, there are other aspects that have to be regarded. On the one hand, it has to be questioned whether this model is the right model for the underlying research problem. On the other hand, it has to be questioned whether this model has been built right to answer the research question. We face the question of validation and verification.

Concerning the validation of the model, the first critique could be that R&D and the search for new knowledge in reality do not take place as assumed in the model. The assumption that firms percolate more or less goal directed from the bottom to the top could be expanded or replaced by the assumption that firms percolate from different centers in the model through the technology space. Here, fitness could be measured as the number of patches away from the technological origin and not as the height of the technological frontier. In addition, the dimension of the model should be expanded as the technology space is far from being a two-dimensional lattice space. The second critique could be the way in which innovations are defined and measured in the model. The model is not able to differentiate between different innovations, but assumes that all innovations in all niches are of the same relevance. Here, one has to think about how to incorporate different kinds of innovations, maybe by measuring breakthrough or radical innovations in terms of firms that are able to change the state of many different patches by one step. The third aspect that can be criticized is the definition of innovative performance in the model. As innovative performance is measured by an increase in the BPF, firms that move to the left or to the right are 'less innovative' and firms that always stay in their niche and move goal-directed are more innovative. This assumption excludes breakthrough or cross-industry innovations and implies that innovations can only happen by marginally improving already existing technology. This could be improved by incorporating percolation through the model as already suggested. If firms start from different places of a more-dimensional world and percolate in different directions of this world, height would not be the only decisive factor. More important could be the distance from the technological origin (independent of the direction). The reader has to be aware that the outcomes that resulted from the model hinge on the way in which movement through the technology space and innovations in the technology space are defined. These results cannot be regarded and interpreted in isolation.

Concerning the verification of the model, one has to differentiate between the basic model and the model with project funding. In the basic model, the first aspect that could be criticized is the homogeneity of the actors in the model. Even though one of the big advantages of ABM is the possibility to work with heterogeneous actors, the model does not make use of this possibility. As we are interested in the effect of project funding on different actors as firms, universities and research organizations, further research should expand the model by heterogeneous actors with different network competencies, different sizes and different absorptive capacities. This would lead to the possibility to investigate the effect of project funding on the innovative performance of different actors and to analyze whether the effect is different for different actors. The second aspect that could be criticized is the fact that even though firms work on the same cells at the same time, they do not cooperate in the narrow sense. However, incorporating cooperation in the model and investigating cooperation in the model could lead to completely different results. Regarding the model with subsidized projects, one point of critique is the assumption that all firms with a subsidized project in their neighborhood can actually participate in a project. However, this is not the case in reality. Not all actors have access to project funding due to self-selection or picking-the-winner behavior of the government. Empirics show that only 15% of all innovative actors participate in subsidized research projects [Handelsblatt, 2009]. Further research should also incorporate into the model that firms act at least bounded rational, i.e. they would not participate in research projects if the grant does not outweigh the R&D costs. As in the basic model, firms in the model with subsidized research projects do not really cooperate, but simply work on the same project at the same time. Again, this has to be improved by further research. In addition, the subsidized research projects could be defined more precisely by defining the number of firms that are allowed to participate in one project, by defining how many actors from different groups can participate in one project, by defining the duration of a project or even by incorporating preferential attachment.

In addition to the validation and the verification of the model, there is another aspect that has to be emphasized. This paper exclusively investigates the effect of project funding on innovative performance. However, innovative performance is not the only aspect that can be influenced by project funding. The instrument of project funding also positively influences joint research efforts, especially between different partners. These joint research efforts are known to have additional positive effects on the innovative performance of firms in an economy [Herstad et al., 2013, p. 495]. Moreover, the knowledge generated in subsidized projects is not kept secret but communicated to the public, which also has positive effects from a welfare point of view. To sum up, even if a more elaborate model can lead to valid results, innovative performance as measured in the model must never be analyzed in isolation.

As the model presented in this paper is a simple basic model, there are numerous possibilities for further research. The most important task would be to extend the model as already suggested above to make it more realistic. This has to be done to investigate whether the effects of project funding on innovative performance are different in a more elaborate model. Furthermore, the model could be extended with real-world data and many different effects could be investigated and confronted with the results of econometric analysis.

The results of the model analyzed in this paper show that, despite the promising approach of agent-based modeling gains in importance in innovation economics, much research still needs to be done. Notwithstanding, the development of computer-aided tools for data evaluation and research as well as the movement away from neoclassical assumptions in combination with an increase in network thinking will lead to a significant change in how research in innovation economics takes place in the future. Therefore, the approach of agent-based modeling is a first step to not only improve the models, methods and tools used in innovation economics, but also to facilitate a change in mind of innovation researchers.

References

Ali-Yrkkö, J. (2005), Impact of public R&D financing on employment, ETLA Discussion Papers, The Research Institute of the Finnish Economy (ETLA), No. 980, 2005.

Almus, M./ Czarnitzki, D. (2003), The Effects of Public R&D Subsidies on Firms' Innovation Activities, Journal of Business & Economic Statistics, 21:2, 226-236, DOI: 10.1198/073500103288618918, 2003.

Arena, R./ Festré, A./ Lazaric, N. (2012), Handbook of Knowledge and Economics, Edward Elgar Publishing, 2012.

Aschhoff, B. (2008), Who Gets the Money? The Dynamics of R&D Project Subsidies in Germany, ZEW Discussion Paper No. 08-018, 2008.

Aschhoff, B. (2009), The Effect of R&D Project Subsidies on R&D Revisited Firms Subsidy History and Subsidy Size, Paper to be presented at the Summer Conference 2009 on CBS - Copenhagen Business School, June 17 - 19, 2009.

Aschhoff, B./ Sofka, W. (2009), Innovation on demand? Can public procurement drive market success of innovations?, Research Policy 38, 2009.

Axelrod, R. (1997), The Complexity of Cooperation: Agent-based Models of Competition and Collaboration, Princeton University Press, Princeton, 1997.

Balci, O. (1997), Verification, Validation and Accreditation of Simulation Models, Proceedings of the 1997 Winter Simulation Conference, 1997.

BMBF Bundesministerium für Bildung und Forschung (2014)A, Fragen und Antworten. URL.: http://www.foerderinfo.bund.de/de/Fragen-und-Antworten-243.php (01.12.2014).

BMBF Bundesministerium für Bildung und Forschung (2014)B, Themen. http://www.foerderinfo.bund.de/de/Themen-898.php (01.12.2014).

BMBF Bundesministerium für Bildung und Forschung (2014)C, Der Förrderkatalog. http://www.foerderinfo.bund.de/de/Themen-898.php (01.12.2014).

BMBF Bundesministerium für Bildung und Forschung (2014)D, Research funding System. http://www.research-in-germany.org/en/research-funding/Research-Funding-System.html (01.12.2014).

BMBF Bundesministerium für Bildung und Forschung (2014)E, Bundesbericht Forschung und Innovation 2014, Publikationsversand der Bundesregierung, Berlin. http://www.bmbf.de/pub/bufi_2014.pdf (01.12.2014).

BMBF Bundesministerium für Bildung und Forschung (2014)F, From the Idea to the Product - Project funding successes II, Publikationsversand der Bundesregierung, Berlin. http://www.bmbf.de/pub/from_the_idea_to_the_product.pdf (08.12.2014).

BMBF Bundesministerium für Bildung und Forschung (2014)G, Daten-Portal des BMBF: Ausgaben des BMBF für Wissenschaft, Forschung und Entwicklung nach Förderbereichen und Fïrderschwerpunkten. http://www.datenportal.bmbf.de/portal/de/Tabelle-1.1.6.html (18.12.2014).

Cantono, S./ Silverberg, G. (2009), A percolation model of eco-innovation diffusion: The relationship between diffusion, learning economies and subsidies, Technological Forecasting and Social Change, Volume 76, Issue 4, p. 487 - 496, May 2009.

Colombo, G./ Grilli, L./ Murtinu, S. (2011), R&D subsidies and the performance of high-tech start-ups, Economics Letters 112 (2011), p. 97 - 99, 2011.

Crooks, A. T./ Hailegiorgis, A.B. (2014), An agent-based modeling approach applied to the spread of cholera, Original Research Article Environmental Modelling & Software, Volume 62, p .164 - 177, Dez. 2014.

Czarnitzki, D./ Ebersberger, B./ Fier, A. (2007), The Relationship between R&D Collaboration, Subsidies and R&D Performance: Empirical Evidence from Finland and Germany, Journal of Applied Econometrics, 2007.

Czarnitzki, D./ Fier, A. (2001), Do R&D subsidies matter? Evidence for the German service sector, ZEW Discussion Papers, No. 01-19, 2001.

Czarnitzki, D./ Hussinger, K. (2004), The Link Between R&D Subsidies, R&D Spending and Technological Performance, ZEW Discussion Papers, No. 04-56, 2004.

Dawid, H. (2006), Agent-based Models of Innovation and Technological Change, in: Tesfatsion, L/ Judd, K. L. (eds.), Handbook of Computational Economics, Volume 2, Chapter 25, 2006.

Ebersberger, B. (2004), Labor Demand Effect of Public R&D Funding, VTT Working Papers 9, 2004.

Fagiolo, G./ Birchenhall, C./ Windrum, P. (2007), Empirical Validation in Agent-based Models: Introduction to the Special Issue, Comput Econ 30, p. 189 - 194, 2007.

FAZ Frankfurter Allgemeine Zeitung (2014), Gastbeitrag: Zukunft durch Forschungsförderung. http://www.faz.net/aktuell/wirtschaft/gastbeitrag-zukunft-durch-forschungsfoerderung-11885467.html (01.12.2014).

Flores, J. C./ Bologna, M./ Urzagasti, D. (2011), A mathematical model for the Andean Tiwanaku civilization collapse: Climate variations, Original Research Article Journal of Theoretical Biology, Volume 291, p. 29 - 32, Dec. 2011.

Fornahl, D./ Broekel, T./ Boschma, R. (2011), What drives patent performance of German biotech firms? The impact of R&D subsidies, knowledge networks and their location, Papers in Regional Science, Volume 90 Number 2, June 2011.

Gabler Wirtschaftslexikon (2014), Stichwort: Freiburger Schule, http://wirtschaftslexikon.gabler.de/Archiv/7246/freiburger-schule-v10.html (20.11.2014).

Garcia, R. (2005), Uses of Agent-Based Modeling in Innovation/New Product Development Research, Journal of product innovation management 22, p. 380 - 398, 2005.

Goldschlag, N. (2013), Percolating Patents: Balancing the Effects of Patents on Innovation, Department of Economics George Mason University, 2013.

Grimmett, G. (1997), Percolation and Disordered Systems, Originally published in: Ecole d'Eté de Probabilités de Saint-Flour XXVI, 1996, 141 Lecture Notes in Mathematics, Vol. 1665, p. 153 - 300, Springer-Verlag Berlin Heidelberg, 1997.

Grimmett, G. R. (1999), Percolation, Grundlehren der mathematischen Wissenschaften, Volume 321, 1999.

Handelsblatt (2009). Handelsblatt (2009), Forschungsförderung erreicht nur Minderheit. http://www.handelsblatt.com/politik/deutschland/staatliche-foerderung-forschungsfoerderung-erreicht-nur-minderheit/3208874.html (01.12.2014).

Harhoff, D. (2000), R&D Spillovers, Technological Proximity, and Productivity Growth - Evidence From German Panel Data, Schmalenbach Business Review, Vol. 52, pp. 238-260, July 2000.

Herstad, S. J./ Aslesenb, H. W./ Ebersberger, B. (2013), On industrial knowledge bases, commercial opportunities and global innovation network linkages, Research Policy 43, p. 495-504, 2013.

Hsua, F./ Hsueh, C. (2009), Measuring relative efficiency of government-sponsored R&D projects: A three-stage approach, Evaluation and Program Planning, Volume 32, Issue 2, p. 178 - 186, May 2009.

Kluger, B. D./ McBride, M. E. (2014), Intraday trading patterns in an intelligent autonomous agent-based stock market. Original Research Article Journal of Economic Behaviour & Organization, Volume 79, Issue 3, p. 226 - 245, Aug. 2011.

Levén, P./ Holmström, J./ Mathiassen, L. (2013), Managing research and innovation networks: Evidence from a government sponsored cross-industry program, Research Policy 43, p. 156-168, 2013

Macal, C. M./ North, M. J. (2007), Agent-based Modeling and Simulation: Desktop ABMs, Proceedings of the 2007 Winter Simulation Conference, IEEE, 2007.

Moran, M./ Rein, M./ Goodin, R. E. (2008), The Oxford Handbook of Public Policy, Oxford Handbooks Online, 2008.

Mort, J. (1991), Perspective: The Applicability of Percolation Theory to Innovation, Journal of Product Innovation Management 8, p. 32 - 38, 1991.

Nelson, R. (1989), What Is Private and What Is Public About Technology?, Science, Technology & Human Values, Vol. 14, No. 3, 229-241, 1989.

Pal, K./ Karakostas, B. (2014), A Multi Agent-based Service Framework for Supply Chain Management, Original Research Article Procedia Computer Science, Volume 32, p. 53 - 60, 2014.

Popescul, D. (2012), Knowledge flows percolation model. A new model for the relation between knowledge and innovation, 2012.

Powell, W. W./ Grodal, S., 2005, Networks of Innovators. In: Fagerberg, J./ Mowery, D. C./ Nelson, R. R. (eds.) (2005), The Oxford Handbook of Innovation, Oxford University Press, U.S.A, 2005.

PwC (2014): The Global Innovation 1000: Comparison of R&D Spending by Regions and Industries. http://www.strategyand.pwc.com/global/home/what-we-think/global-innovation-1000/rd-intensity-vs-spend (10.12.2014).

Pyka, A./ Fagiolo, G. (2005), Agent-Based Modelling: A Methodology for Neo-Schumpeterian Economics, Institut für Volkswirtschaftslehre der Universität Augsburg, Volkswirtschaftliche Diskussionsreihe, #272, 2005.

Roozmand, O./ Ghasem-Aghaee, N./ Hofstede, G. J./ Nematbakhsh, M. A./ Baraani, A./ Verwaart, T. (2011), Agent-based modeling of consumer decision making process based on power distance and personality, Original Research Article Knowledge-Based Systems, Volume 24, Issue 7, p. 1075 - 1095, Oct. 2011.

Shante, V. K. S./ Kirkpatrick, S. (1971), An introduction to percolation theory, Advances in Physics, 20:85, p. 325 - 357, 1971.

Silverberg, G./ Verspagen, B. (2005), A percolation model of innovation in complex technology spaces, Journal of Economic Dynamics & Control 29, p. 225 - 244, 2005.

Silverberg, G./ Verspagen, B. (2007), Self-organization of R&D search in complex technology spaces, Journal of economic interaction and coordination, 2(2), p. 211 - 229, 2007.

Spektrum der Wissenschaft (1999), Was bringt die EU-Forschungsförderung?. http://www.spektrum.de/alias/dachzeile/was-bringt-die-eu-forschungsfoerderung/825223 (08.12.2014).

Wanka, J. (2014), Hightech-Strategie: "Deutschland muss jetzt auch Innovations-Weltmeister werden", in: EurActiv.de, http://www.euractiv.de/sections/innovation/hightech-strategie-deutschland-muss-jetzt-auch-innovations-weltmeister-werden (20.10.2014).

Zeppini, P./ Frenken, K. (2013), Innovation diffusion in networks: the microeconomics of percolation, 2013.

Appendix - A

Parameters	Typical Model Run
steps	20*100
no. of firms	30
mean resistance	15
st. dev. resistance	10
search radius	3
start R&D-budget	100
venture capital	1
payoff per inno.	35

Table 2: A typical model run used to replicate stylized facts. Own Table.

Appendix - B1

Test	**Definition**
Test 1:	Effect of technology space complexity on max BPF and number of innovations.
Test 1a:	Effect of technology space complexity on max BPF and number of innovations dependent on search radius.
Test 1b:	Effect of technology space complexity on max BPF and number of innovations dependent on venture capital.
Test 1c:	Effect of technology space complexity on max BPF and number of innovations dependent on venture capital and research grants.
Test 2:	Effect of number of projects on max BPF and number of innovations.
Test 2a:	Effect of number of projects on max BPF and number of innovations dependent on search radius.
Test 2b:	Effect of number of projects on max BPF and number of innovations dependent on venture capital.
Test 2c:	Effect of number of projects on max BPF and number of innovations dependent on venture capital and research grants.

Table 3: Test 1a - 2c used to investigate the effects of project funding on innovative performance. Own Table.

Appendix - B2

Test	Definition
Test 3:	Effect of technology space complexity on mean trajectory change.
Test 3a:	Effect of technology space complexity on mean trajectory change dependent on search radius.
Test 3b:	Effect of technology space complexity on mean trajectory change dependent on venture capital.
Test 3c:	Effect of technology space complexity on mean trajectory change dependent on venture capital and research grants.
Test 4:	Effect of number of projects on mean trajectory change.
Test 4a:	Effect of number of projects on mean trajectory change dependent on search radius.
Test 4b:	Effect of number of projects on mean trajectory change dependent on venture capital.
Test 4c:	Effect of number of projects on mean trajectory change dependent on venture capital and research grants.

Table 4: Test 3a - 4c used to investigate the effects of project funding on innovative performance. Own Table.

Appendix - C

Parameters	**Test 1a**	**Test 1b**	**Test 1c**	**Test 2a**	**Test 2b**	**Test 2c**	**Test 3a**	**Test 3b**	**Test 3c**	**Test 4a**	**Test 4b**	**Test 4c**
steps	10*100	10*100	10*100	10*100	10*100	10*100	10*100	10*100	10*100	10*100	10*100	10*100
no. of firms	30	30	30	30	30	30	30	30	30	30	30	30
mean resistance	0.5-30	0.5-30	0.5-30	15	15	15	0.5-30	0.5-30	0.5-30	15	15	15
st. dev. resistance	10	10	10	10	10	10	10	10	10	10	10	10
search radius	2 & 5	3	3	2 & 5	3	3	2 & 5	3	3	2 & 5	3	3
start R&D-budget	30	30	30	30	30	30	30	30	30	30	30	30
venture capital	1	1 & 10	5 & 25	1	1 & 10	5 & 25	1	1 & 10	5 & 25	1	1 & 10	5 & 25
payoff per inno.	35	35	35	35	35	35	35	35	35	35	35	35
no. of projects	55	55	55	0-250	0-250	0-250	55	55	55	0-250	0-250	0-250
projects radius	5	5	5	5	5	5	5	5	5	5	5	5
grant money	10	10	25	10	10	25	10	10	25	10	10	25

Table 5: Different test-parameters used to investigate the effects of project funding on innovative performance. Own Table.

Appendix - D1

Test	β	$p-value$	R^2	$adj.R^2$
1a (a) - max BPF basic	-3,66	0,00	0,95	0,94
1a (a) - max BPF project	-0,97	0,00	0,75	0,73
1a (b) - max BPF basic	-3,33	0,00	0,82	0,80
1a (b) - max BPF project	-1,98	0,00	0,89	0,88
1a (a) - no. of inno. basic	-33,96	0,00	0,90	0,90
1a (a) - no. of inno. project	-5,27	0,00	0,89	0,88
1a (b) - no. of inno. basic	-30,76	0,00	0,91	0,90
1a (b) - no. of inno. project	-5,65	0,00	0,85	0,83
1b (a) - max BPF basic	-3,71	0,00	0,91	0,90
1b (a) - max BPF project	-1,51	0,00	0,82	0,81
1b (b) - max BPF basic	-2,35	0,00	0,88	0,86
1b (b) - max BPF project	-0,33	0,00	0,51	0,47
1b (a) - no. of inno. basic	-73,18	0,00	0,92	0,92
1b (a) - no. of inno. project	-28,05	0,00	0,82	0,80
1b (b) - no. of inno. basic	-33,23	0,00	0,86	0,85
1b (b) - no. of inno. project	-4,00	0,00	0,68	0,65
1c (a) - max BPF basic	-3,22	0,00	0,93	0,93
1c (a) - max BPF project	-0,29	0,00	0,64	0,61
1c (b) - max BPF basic	-0,68	0,00	0,77	0,74
1c (b) - max BPF project	-0,12	0,00	0,64	0,60
1c (a) - no. of inno. basic	-73,18	0,00	0,93	0,92
1c (a) - no. of inno. project	-11,37	0,00	0,77	0,75
1c (b) - no. of inno. basic	-32,17	0,00	0,88	0,87
1c (b) - no. of inno. project	-3,01	0,00	0,55	0,51

Table 6: Test statistics for test 1. Own table.

Appendix - D2

Test	β	$p-value$	R^2	$adj.R^2$
2a (a) - low SR	-0,00	0,04	0,50	0,42
2a (a) - high SR	-0,01	0,05	0,49	0,40
2a (b) - low SR	-0,57	0,00	0,85	0,83
2a (b) - high SR	-0,02	0,00	0,03	0,00
2b (a) - low VC	-0,00	0,10	0,37	0,26
2b (a) - high VC	-0,00	0,22	0,23	0,11
2b (b) - low VC	-0,97	0,00	0,82	0,80
2b (b) - high VC	-0,80	0,00	0,76	0,72
2c (a) - low VC	-0,00	0,06	0,47	0,36
2c (a) - high VC	-0,00	0,06	0,44	0,35
2c (b) - low VC	-0,75	0,00	0,86	0,84
2c (b) - high VC	-0,67	0,00	0,72	0,67

Table 7: Test statistics for test 2. Own table.

Appendix - D3

Test	β	$p-value$	R^2	$adj.R^2$
3a (a) - basic	0,20	0,00	0,87	0,86
3a (a) - project	0,04	0,00	0,50	0,45
3a (b) - basic	0,11	0,00	0,90	0,90
3a (b) - project	0,02	0,00	0,50	0,45
3b (a) - basic	0,27	0,00	0,95	0,95
3b (a) - project	0,08	0,00	0,80	0,78
3b (b) - basic	0,15	0,00	0,90	0,89
3b (b) - project	0,01	0,03	0,34	0,28
3c (a) - basic	0,27	0,00	0,95	0,95
3c (a) - project	0,01	0,04	0,31	0,25
3c (b) - basic	0,15	0,00	0,87	0,85
3c (b) - project	0,01	0,25	0,11	0,03
4a (a) - low SR	0,01	0,00	0,84	0,82
4a (a) - high SR	-0,00	0,83	0,00	0,00
4b (b) - low VC	0,01	0,00	0,83	0,80
4b (b) - high VC	0,02	0,00	0,92	0,91
4c (c) - low VC	0,00	0,05	0,48	0,40
4c (c) - high VC	0,01	0,00	0,92	0,91

Table 8: Test statistics for test 3 and 4. Own table.

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