# An Agent-Based View of the Biotech Innovation System

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## Abstract

*This paper develops an agent-based model of the biotechnology innovation system with the purpose to analyze the effects of public RTI (Research, Technology and Innovation) funding on innovative performance. Biotechnology is characterized as a research-intensive field where industrial and scientific agents operate in a highly dynamic environment. Interdependencies among agents are manifold, fostering dynamics and complexity in the system. While current agent-based models of the system have focused on the creation and exchange of knowledge among firms, this paper directs attention to public RTI funding and the impact on agent behavior in the system. The paper is methodological in nature, with the life sciences cluster of the Vienna region in mind that will be used as basis for empirical testing in a later stage of the project.*

**Key words:** Complexity, agent-based modeling, sectoral innovation systems, biotechnology

**JEL Classification:** C63, O32, O38, D83

## 1 Introduction

Biotechnology is a young, research-intensive field that may be defined as “the application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or nonliving materials for the production of knowledge, goods and services” ([1], p. 7). Industrial and scientific agents in biotechnology face a dynamic environment characterized by fast-expanding scientific knowledge and scattered expertise. The ability to create innovations is crucial for the competitiveness of firms, and high development costs are associated with long time lags in the commercialization of scientific results [2]. Thus, agents operate under high uncertainty, and, in order to keep pace with innovation, they engage in R&D networks [3]. This cooperation in R&D creates relations and flows between the agents. Interdependencies foster dynamics and complexity in the biotech system.

We view biotechnology as a sectoral innovation system[1] which is characterized by interdependent agents and their non-linear interactions (e.g. [11], pp. 74-75; [12], pp. 3-4; [13], p. 369; [14]). The sectoral innovation system [15-16] consists of a set of firms active in developing and making a sector's products and in generating and utilizing a sector's technologies. Processes of interaction and cooperation in technology development as well as processes of competition and selection in innovative and market activities form the relations within the system ([15], p. 131).

The objective of this paper is to suggest an agent-based model that allows for a considerable degree of heterogeneity among the agents and their interactions. Heterogeneity of both types appears to characterize the biotech innovation system. We take a systemic view on the system, and consequently identify the elements and agents of the system and their relations. This is due to the specific importance of systemic behavior and learning in this sector. The resulting performance of such a system can be more than the sum of its parts ([17], p. 1649).

The explosive growth in computer power over the past decades has shifted interest on agent-based computational models, computationally intensive methods for developing and exploring new kinds of economic models. Agent-based models allow the computational study of innovation processes modeled as dynamic systems of interacting agents who do not necessarily possess perfect rationality and full information. Whereas conventional models require a careful consideration of equilibrium properties ([17], pp. 1649-1650; [18], pp. 351-352; [19], pp. 884-885; [20]), agent-based models stress innovation processes, interactions among economic agents, and out-of-equilibrium dynamics. Agent-based models require detailed specifications of structural conditions, institutional arrangements, and behavioral dispositions ([21], pp. 843-865; ([19], p. 885); ([22-23]).

Agent-based modeling (ABM) is well suited for analyzing innovation systems exhibiting the following two properties: (a) the system consists of interacting agents, and (b) the system exhibits emergent properties, i.e., properties arising from the interactions of agents that cannot be deduced simply by aggregating the properties of these agents. When the interaction of agents is contingent on past experience, and when the agents continually adapt to that experience, mathematical analysis is characteristically rather limited in its ability to derive the dynamic consequences [17].

An agent-based model allows to enhance our knowledge not only about the processes of variety creation and selection, but also – and most importantly – about the co-evolution of the system ([16], pp. 251-262). In a later stage of the project the model will be empirically calibrated, using the life sciences cluster of the Vienna region as reference.

This life sciences cluster ([24], p. 7), consisting mainly of red and green[2] biotech organizations, essentially goes back to a joint venture of Boehringer Ingelheim and Genentech in the mid-1980s ([25]) that sparked off new dynamic activities, and has gained momentum since then. It is worth noting that the focus of Vienna's research policy is on biotechnology since 2003, and specific calls for research projects in this field are offered on a regular basis ([26]).

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[1] See detailed information on innovation systems [4-5], on regional innovation systems [6-7] and on national innovation systems [8-10].

[2] Red biotechnology is the definition for research and application in medical and pharmaceutical science and includes the whole range from diagnostics to therapy. Green biotech covers agricultural and food biotechnology ([1], p. 88).

The paper is organized as follows. Section 2 briefly describes the agent-based modeling approach. Sections 3 directs attention to the core agents in the system (industry, university, and research organization agents) characterized by specific knowledge endowments, while Section 4 focuses on the relations between these agents of various form, including interaction, and knowledge, labor and financial flows. Section 5 moves to the issue of how to measure the performance of the biotech innovation system. Section 6 briefly discusses the role of public RTI funding in the system. The paper closes with a brief outlook.

## 2 The biotech innovation agent system

A system of innovation can be considered to consist of a set of actors or entities such as firms and other organizations that interact in the generation, use, and diffusion of new – and economically useful – knowledge in the production process. The systems of innovation approach provides an important framework for understanding why some firms, sectors or regions are economically successful while others are not. The attractiveness of the systems approach stems from three features ([27], p. 15):

- First, it places innovation and knowledge creation at the very center of focus, and goes beyond a narrow view of innovation to emphasize its interactive and dynamic nature.
- Second, it represents a considerable advance over the network school of innovation [28], due to the decisive shift in focus from firm to sector or territory, from the knowledge-creating firm to the knowledge-creating sector or territory.
- Third, it views innovation as a social process which is institutionally embedded, and hence lays special emphasis on the institutional context and the forms in which, and through which, the process of knowledge creation and dissemination occurs.

Three types of innovation analysis may be performed, depending on the context ([27], p. 15):

- the first refers to the micro-level of the system and attempts to analyze the internal capabilities of selected firms and the links surrounding them (knowledge relationships with other firms and with non-market organizations);
- the second refers to the meso-level of the system and focuses on specific subsystems and attempts to map knowledge and other interactions within and between subsystems;
- the third refers to the macro-level of the system and typically involves the use of macro-indicators, such as R&D personnel ratios, R&D expenditure intensity rates, patent intensity rates, and network indicators of various kinds which characterize the system in general terms.

**Fig. 1 The biotech innovation system as a black box**

Figure 1 views the biotech innovation system from a macro-level perspective with financial resources as key input factor and R&D results of different kind as output of the system. The attraction of financial resources is an important concern of all agents in order to perform R&D projects [29]. Organizations finance their projects either internally or externally, or as a mixture of both. Exclusively internal financing implies the reinvestment of cash flow, e.g. of the profit made through the successful commercialization of innovative products. Apart from public RTI funding, venture and debt capital play an important role in financing R&D projects. Government funds build the focus of our simulation project and are divided into direct funding, initiated bottom-up (by the organization) or top-down (by the government), and indirect funding, institutional funding or the creation of competence centers. Indirect funding includes tax allowances or the deduction of R&D expenses from tax. The output of the innovation system is measured in terms of patents, publications, and the creation of high-tech jobs.

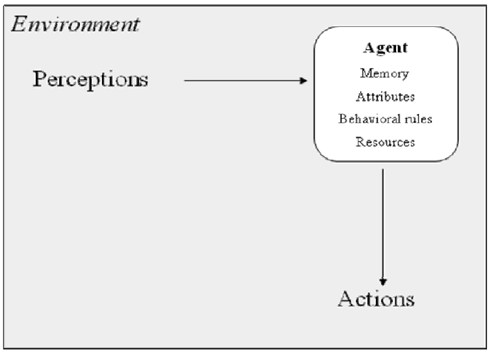

**Fig. 2 An agent embedded in its environment**

The agents in our model are conceptualized as heterogeneous agents with respect to their perceptions, actions, and internal attributes ([30], pp. 3-5). As indicated in Fig. 2, an agent uses its knowledge to communicate ([31], p. 48) and memorize information[3], and is viewed to act according to behavior rules in order to reach a certain goal. An agent may refine its decisions in the course of time as it perceives its environment, responds to it, and learns from it. The agent is autonomous [33] and might operate alone, although, thanks to its social ability it interacts with others as well ([34], pp. 118-119). The internal state of an agent and its actions change the environment of the others. Beside the simulation of interactions between agents ([35], p. 381), the integration of multilevel feedback effects is rendered possible ([36]).

By including different types of agents and their strategies, our model draws on previous research ([37-38]), in particular on the SKIN model ("Simulating knowledge dynamics in innovation networks") developed by Gilbert, Ahrweiler, and Pyka ([38]) that focuses on market interaction and knowledge exchange among firms.

We depart from previous research in several aspects. First, we take explicitly public sector research, such as universities and public research organizations, and different types of public

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[3] While information is factual and provides an answer to the question "what?" regarding a certain situation, knowledge is complex and tries to answer the "why?" and "how?" ([32], p. 348).

funding into account, and second, we focus on analyzing the effects of policy intervention in a localized biotech innovation system.

While the SKIN model represents a reductionist approach which according to the KISS[4] belief is designed as simple as possible [39], our model attempts to provide a more realistic view based on the principle of KIDS[5] [40]. The KIDS approach is related to models which emphasize the examination of factors and dynamic processes characteristic for the evolution of industries. By relying on work by Malerba and Orsenigo ([41], p. 667), we suggest a case-based model of the Vienna biotech innovation system which is sufficiently detailed in terms of time and space. Knowledge-related processes and political interventions regarding knowledge production and exchange are at the core of the model.

## 3 The agents: Assumptions and behavioral dispositions

The agent-based model distinguishes three types of core agents: university, research organization, and industry agents. While the "university agents" include not only universities but also universities of applied sciences (the Austrian "Fachhochschulen"), "research organization agents" involve public or private non-profit research organizations. "Industry agents" include large diversified pharmaceutical firms (LDFs), multinational companies, smaller dedicated biotech firms (DBFs) ([42], p. 79), but also start-up and spin-off companies. This variety is modeled by different attribute values for the particular agent type. Further agents considered are financial organizations such as banks that allow credits or venture capitalists which organize private capital for the agents' investments. Moreover, note that governmental authorities, or public innovation policy agencies are important determinants of innovation in any innovation system ([4], p. 2 and [43], pp. 3-5).

Behavioral dispositions are characterized by specific knowledge endowments (a set of "kenes", [44], pp. 8-10) and other attribute values that govern the exchange processes among agents. Every agent is characterized by a set of kenes (see Table 1) representing its knowledge endowment. A kene is a triple of variables incorporating capabilities (Cs), core competencies (CCs), and a particular expertise level (E). The agent is able to modify or expand its kene set through own R&D efforts or cooperation with other agents during joint R&D activities. No matter whether carried out alone or in collaboration, R&D is costly on the one hand, but, on the other hand it leads to the acquisition of new capabilities and core competencies for the agent's kenes.

**Table 1 Kene structure**

| Kene element | Code | Scale type | Value |
|---|---|---|---|
| Capability | C | Categorical | see Table 2 |
| Core competence | CC | Categorical | see Table 3 |
| Expertise level | E | Ordinal | 1, …, 10 |

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[4] "Keep It Short, Stupid"

[5] "Keep It Descriptive, Stupid"

Note that the capabilities (Cs) of an agent may relate to a scientific or technological field, or a business domain (see Table 2), while the core competencies (CCs) relate to specific competencies within the particular C as outlined in Table 3. In contrast to Pyka et al. [42], we define capabilities in terms of categorical rather than metric variables. As a concept of proximity on the set of capabilities, we employ the number of co-occurrences of two capabilities (activity domains) in the agent population, and use the respective Jaccard-Index [45] as a measure of thematic proximity of these capabilities.

**Table 2 Specification of the agent's capabilities**

| C | **Capability in a scientific, technological or business domain** |
|---|---|
| 1 | Analytical methods & services |
| 2 | Antibodies |
| 3 | Bacterial & viral diseases / Antiinfectives |
| 4 | Cardiovascular diseases |
| 5 | Cell & tissue culture |
| 6 | Clinical research & tests |
| 7 | Consulting |
| 8 | Dermatology |
| 9 | Diagnostics / Diagnostic technologies |
| 10 | Drug development / Drug delivery |
| 11 | Environmental issues |
| 12 | Enzymology / Protein engineering / Fermentation |
| 13 | Gene & cell therapy, viral vectors |
| 14 | Genomics |
| 15 | Immunology / Allergology |
| 16 | Industrial processing |
| 17 | Informatics in the life sciences |
| 18 | Lab equipment, medical & surgical equipment |
| 19 | Metabolomics |
| 20 | Medical technology & devices |
| 21 | Microbiology |
| 22 | Nanobiotechnology |
| 23 | Neurobiology / Neurodegenerative diseases |
| 24 | Nutrition / Food / Feed |
| 25 | Oncology |
| 26 | Pharmaceuticals |
| 27 | Plant breeding & genetics |
| 28 | Proteomics |
| 29 | Process technology |
| 30 | Regenerative medicine |
| 31 | Services (synthesis, sequencing, spectroscopy) |
| 32 | Stemcells |
| 33 | Structural biology |
| 34 | Vaccines |
| 35 | Veterinary activities |
| 36 | Others |

*Note: C denotes capability and ranges from 1 to 36.*
*Source: Austrian Life Sciences Directory 2009* [46].

**Table 3 Specification of the agent's core competencies**

| CC | **Core competence within a particular capability (C)** |
|---|---|
| 1 | R&D |
| 2 | Contract research |
| 3 | Production & processing |
| 4 | Marketing |
| 5 | Service |
| 6 | Education & training |
| 7 | Management |
| 8 | Others |

*Note: CC denotes core competence and ranges from 1 to 8.*
*Source: Austrian Life Sciences Directory 2009* [46].

We assume that particular core competencies (CCs) as displayed in Table 3 dominate the operations of the agent. Both, capabilities and core competencies are measured in terms of nominal variables. Every agent reaches a certain expertise level within each of its capabilities (C) which indicates the acquired know-how in the particular technological capacity over the time steps in the course of the simulation ([42], p. 173).

Finally, agents are not only characterized by this knowledge endowments, but also by other attributes as entitled in Table 4 that are widely viewed to be crucial for agent behavior. Examples include the capital structure of the agent, its R&D infrastructure, absorptive capacity[6], cooperation behavior, search strategy for partners, an agent's application orientation[7] and R&D strategy, etc.

**Table 4 Further agent attributes**

| Attribute name | Code | Scale type | Value |
|---|---|---|---|
| Application orientation | AO | Dichotomous | Basic research, Applied research |
| Absorptive capacity | AC | Ordinal | 1, …, 10 |
| Research attitude | RA | Dichotomous | Incremental, Radical |
| R&D strategy | RS | Dichotomous | Go-it-alone, Collaborative |
| Partner search strategy | PS | Dichotomous | Conservative, Progressive |
| Cooperation behavior | CB | Dichotomous | Imitative, Collective |
| Capital stock | CS | Ratio | |
| R&D infrastructure | I | Ordinal | 1, …, 10 |

We assume that the generation of innovation is embedded in processes of learning[8] by doing, learning by using, and learning by interacting ([47], p. 254), and every simulation period that leads to a successful innovation gives rise to an increase of the agent's expertise level (E) by one. On the other hand, the expertise levels of capabilities which are not included in the invention decline by one until the respective E levels drop to zero. As a consequence, this capability is forgotten and eliminated from the agent's kene ([42], p. 174). The same is valid for learning by interacting, i.e., only knowledge which is actively used by the agents in a partnership or a network, and an invention is created, increases an agent's knowledge base.

Agents decide whether they prefer to do exclusively own R&D and therefore follow the go-it-alone strategy or they desire to cooperate and start looking for a partner. They might follow a conservative or progressive strategy in searching for cooperation partners. Whereas the conservative strategy implies a preference for potential partners with similar capabilities, progressive partner search concentrates on different capabilities ([38], p. 103).

Collaboration might be realized according to an imitative or a collective strategy. While the first option excludes own research and focuses only on imitation, the latter collaborative strategy comprises in-house as well as joint research ([42], p. 176). With respect to potential partner search, the attractiveness of previous partners is the highest. A check of the potential partner's inventive capabilities is assumed to build the basis for the decision ([38], p. 103). Cooperation experience is taken into account as past success and failures are reported ([48], pp. 6-13). Agents might choose to perform own research as well as to participate in R&D partnerships and networks simultaneously.

In addition, agents, partnerships or networks might opt for performing incremental or radical research. On the one hand, if an agent has enough capital, it can afford to do incremental research

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[6] An agent's absorptive capacity (AC) refers to its ability to integrate pieces of external knowledge into its own knowledge stock during collaborative R&D ([32], p. 344).

[7] "research direction" ([38], pp. 102-103)

[8] Learning is the acquisition and application of new information and skills and is considered as "a critical component in the development of continuous innovation for organizations" ([32], p. 345).

which involves R&D in the company's laboratories. One of the agent's capabilities is selected and changed according to the specific research direction of the agent. The related expertise level is marked down to one ([37], pp. 5-7). If R&D is performed by a partnership or a network, the research direction held by the majority of the participating agents is chosen. In the course of the simulation, the research direction reacts to previous success as research continues towards the same direction or failure which comprises the selection of a completely different capability of its kene set. Alternatively, an agent opts for radical research if it faces the danger of bankruptcy. Therefore, it investigates entirely diverse market opportunities, generates a new capability (C) for its kene, and creates a new invention ([38], pp. 102-103). Radical research performed by partnerships and networks are subject to the same process.

## 4 Interactions among agents

Interdependencies among agents in the biotech innovation system are manifold. Figure 3 outlines the relations between the various core types of agents. The relations between university agents and industry agents are described in more detail as they are most important in the model. R&D cooperation between university agents and industry agents in Austrian biotechnology takes place in various ways. Collaborative R&D in bilateral partnerships or networks, such as the work on co-patenting and co-publications, results in knowledge flows between the agent types.

International competence centers are taken into account as special cases of science and industry cooperation [49]. Further formalized knowledge interactions between companies and universities occur during sabbatical periods and through consulting by university members, joint research programs, and lectures held by firm members at universities. Moreover, firms use university facilities, or buy prototypes which have been developed at universities. One of the major problems concerning cooperation is red tape, i.e., the involvement in bureaucratic and non-research activities.

The creation of spin-off companies represents a particular knowledge flow linking academia with the business world. University members hold company stakes and/or create start-up companies ([50], p. 305). Sometimes spin-off companies also grow out of companies or research organizations, consequently, facilitating information flows.

Further knowledge flows arise through contract research that universities or research organizations perform for industry agents. In the model contract research is realized by the exchange of kenes and as remuneration a money flow compensates the research effort.

Labor mobility creates knowledge flows between agents. Highly skilled human resources in Vienna's biotechnology create knowledge flows due to job changes between science and industry. Up to now, labor mobility is not so highly-developed between companies within the industry and of course occurs not only on a local level as much importance is attributed to international labor mobility as well ([51], p. 361). Related to this issue, an analysis of key personalities and their labor mobility in the biotech sector will reveal the knowledge linkages between organizations.

Adjunct teaching is very common since biotech specialists and managers often give lectures in educational organizations. This channel is a rather formalized interaction type triggering personal contact and possibly transfers of tacit knowledge.

Another channel is created by licensing agreements linking e.g. firms that license university patents. Denoting a rather formal agreement, licensing creates less tacit knowledge exchange and requires less personal contact ([52], p. 138).

Less formalized forms of knowledge interactions come from the joint supervision of master and PhD theses, the employment of graduates by industry agents, and the training of firm members. An intense transfer of tacit knowledge, without any formal agreements, occurs during conferences, informal meetings, and joint publications. In addition, the reading of publications and patents creates common knowledge in a certain field ([50], p. 305).

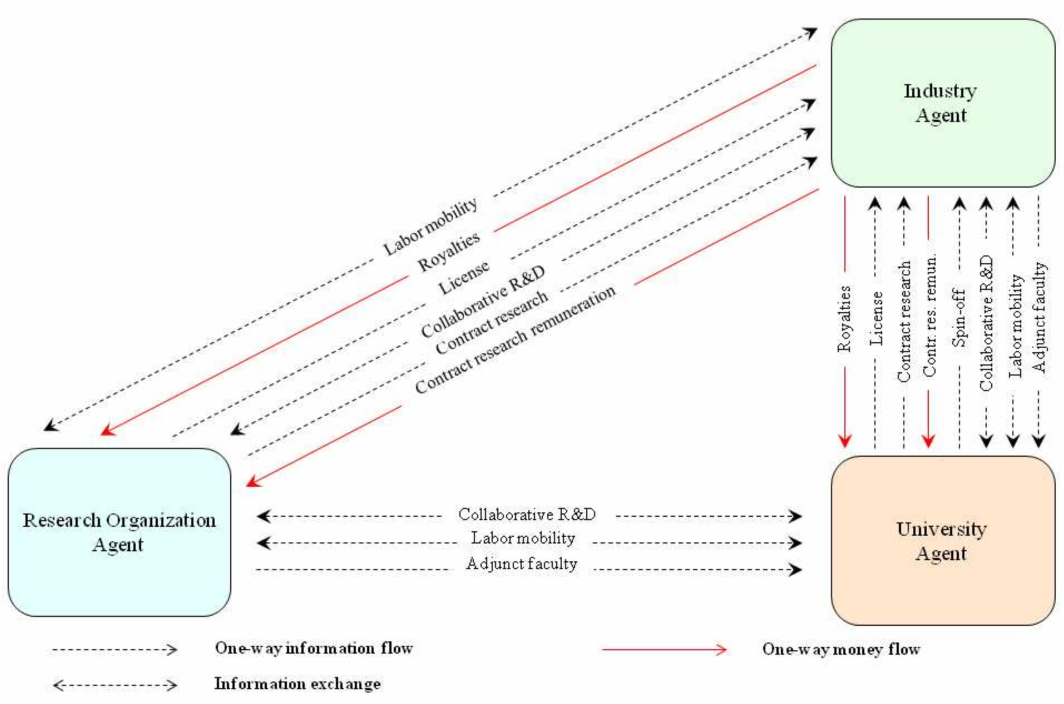

**Fig. 3 Agent types and their relations**

We assume that agents interested in collaboration look for potential partners and inspect their qualities at each time step. The higher the number of capabilities that the agents have in common, the more easily external knowledge is integrated into the own kene set. If both agents agree, the cooperation starts and the agents' kenes are modified as a result. The modification of the agents' kenes takes place as follows: If capability (C) is the same as the kene set copied by the partner, the C with the highest expertise level (E) is selected from the set ([37], p. 6). Due to the fact that integration of new, external knowledge is difficult (e.g. [53]), the E level of the respective C is downgraded to one ([42], p. 178). In the end, the agent and its partner have consolidated their kene sets used in the cooperative invention.

Networks emerge out of bilateral cooperation and are long-lasting collaborations linking more than two agents. Apart from the fact that internal coordination costs of joint R&D within networks are lower and that entry barriers are higher, networks follow similar rules as partnerships do. Agents are invited by network members if they have been in former partnerships with them. The new member accepts this invitation if he has not yet become member of another network. Networks may decide to perform incremental or radical research as well as further collaboration like other agents ([42], p. 180).

## 5 Measuring the performance of the system

R&D results are usually measured in terms of publications and patents. Since intellectual property is an important issue in science-industry relations, output measurements of collaborative research projects have to take into account different levels of output, which are associated with different scientific and commercial value. In biotechnology joint publications are often released only after a written agreement by the company. During negotiations the patent owner has to be determined – while some universities prefer to retain the patent, others tend to ask for money as a compensation for their research [49].

In the model, we use three different levels of output items: Working documents, publications, and patents. We assume that every agent aims to increase the number and quality of output items. In order to operate successfully in the biotech innovation system, agents have to decide according to their specific strategies. An agent uses its knowledge characteristics and attributes to create "inventions"[9]. An invention[10] consists of a small subset of the agent's kenes and characteristics which are seen as key competencies. Inventions are the result of research projects and show the agents current specialization during partner search. An agent saves information in a memory up to two time steps. This information includes the composition of its last invention and whether it has been commercialized as a product on the market, published as an article, and so on. Moreover, the cooperation experience ([48], p. 7) is memorized as it serves as a basis of decision-making in partner selection.

In the simulation, the agents have the choice to propose their invention to venture capitalists, to potential buyers on the market, or to the public funding agency. There are three different levels of evaluation of R&D projects during the simulation run:

- First, before project start, agents and project groups may decide to submit proposals to receive public funding. The outcome of this evaluation phase is a go or no-go decision of government regarding the particular R&D project.
- On the next evaluation level, R&D projects might result in working documents, publications, or patents.

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[9] An invention is a new idea before its commercialization ([32], p. 344).

[10] "innovation hypothesis" ([42], pp. 174-178)

- If the outcome of an R&D project is a patent, agents might opt for addressing venture capitalists in order to receive money for their research. Potential venture capitalists will evaluate the research outcome carefully, before they provide financing. A similar mechanism occurs if the agents aim at market commercialization of their R&D outcome.

The invention submitted by the agents defines a particular co-ordinate in a multi-peaked and multidimensional landscape. The height of this point reveals the financial reward and if this exceeds a certain threshold, e.g. public RTI funding is granted in order to promote the agent's R&D activities. After this procedure, the landscape is reshaped at this particular co-ordinate and its surroundings so as to avoid rewarding the same innovation repeatedly. Certainly, imitation might be attracted and therefore, the rewards for the neighboring points are slightly increased ([42], pp. 175-181).

The market evaluates the innovations according to the market mechanism between supply and demand. If an innovation is a high-quality product at a lower price in comparison to its competitors, it is purchased by end-users and other agents. The price for an innovation rises if the demand is high. If there is no demand for a certain innovation, the price is reduced until it reaches the level of production costs ([38], pp. 101-102). The commercialization of innovations on the market increases the agent's capital stock ([37], p. 6). Performing contract research does not only provoke knowledge flows but affects the capital stock as well and leads to a rise of a fixed amount per period, therefore, causing money flows to research organizations and universities which derive mainly from industry agents.

As project members share their knowledge and research results, they have to divide their rewards for successful inventions. If the joint invention results in a successful innovation, the agents share the reward according to their capital stock, i.e., the richer partner receives a higher proportion of the reward ([37], p. 7), and according to their relative involvement in the invention process. After a long period of continuous failures, i.e., the submission of unsuccessful inventions, the network is dissolved and agents come back to individual R&D ([42], p. 180).

In the biotech sector, a particularly successful and profit-making incumbent attracts start-ups. The creation of new agents is of striking importance for the dynamics in a sectoral innovation system as it generates variety e.g. regarding different strategies. In order to reflect the diffusion of economically relevant know-how, a new company is added to the agent population as a clone with a kene set limited to that of the successful innovator. So as to represent the lack of experience and initial capital, the start-up's expertise level is set to one and the capital stock is decreased as well ([38], pp. 103-104). While at the beginning a start-up company is dependent on public RTI funding, later it is able to attract private investors as well.

## 6 The role of public RTI funding

The model is intended for later simulation of public RTI funding regimes facing the complexity of the biotech innovation system as highlighted above. Regarding RTI policy in Austria, considerable weight has been put on indirect funding, i.e., tax incentives for R&D, in the last few years. Despite a fundamental reform of the university sector, institutional funding by the government is to a large extent absorbed by universities, while the non-profit research sector is small in an international comparison. Direct funding (government programs) exists on national as well as on regional levels, and includes measures supporting R&D collaboration, and also a more institutionalized form of collaboration between science and industry, so-called competence centers, which are relevant for the life sciences sector in Vienna.

Public funds comprise institutional funding granted specifically to science agents, whereas program and project funding goes to science as well as to industry agents. In a recent analysis of R&D networks in the Vienna life sciences sector, 136 projects in eight funding programs were identified. Out of this number, two programs are European, namely the “Life Quality” program in the 5th EU framework program as well as “Medical and Biotechnology” in EUREKA. The national funding activities comprise the Austrian NANO initiative, the GEN-AU Genome Research Austria [54] in addition to five specific competence centers. To be emphasized here is the fact that Viennese organizations are largely involved in European projects (87%), and less on a national (6%) or regional (7%) level ([55], p. 162).

Generally, it is often criticized that the funding system in Austria is too complex and confusing, and that for some research stages (e.g. clinical research phase 2) funding is not provided at all. Specifically, the nonexistence of standardized contracts, fundraising, and accounting for funding institutes claim considerable time which could be used for core business [49].

Public RTI policy aims to improve possibilities offered to regional companies and organizations regarding access and use of funding support, and promote regional innovation potential ([56], p. 133). For a localized sectoral innovation system like the Vienna biotech sector, it is important how effective public interventions are in the creation of sustainable dynamics within the cluster and its relations with the outside world. It is the main goal of this modeling exercise to analyze and compare the effects of different funding types in a localized biotech innovation system regarding collaborative and innovative performance. Hereby, the various types of direct funding – with or without requirement for interorganizational cooperation – can be compared to indirect funding and also with the “no-policy” case.

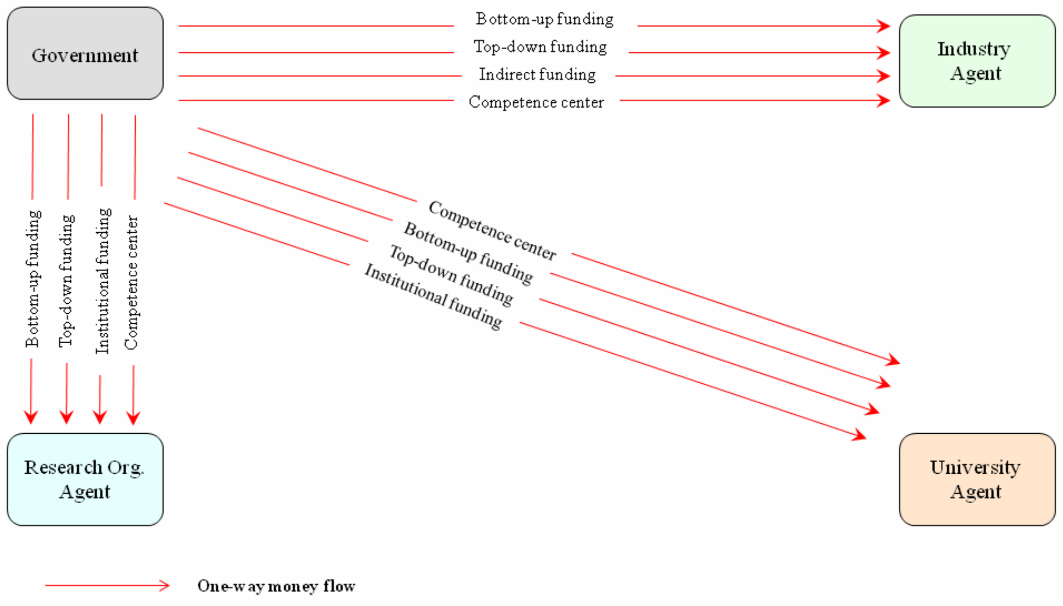

**Fig. 4 Public RTI funding as a financial resource**

Government-funding for R&D with the requirement to cooperate triggers the structure of collaboration networks which influences the agent-specific knowledge output in a dynamic way. This belief has governed RTI policy throughout Europe in the last decades, and it continues to do so as well on the regional level. As illustrated above in Fig. 4, public RTI funding realizes money flows from the "government" component to industry, university and research organization agents. Government provides not only science agents with institutional funding but also governmental funding for programs and projects for science as well as industry agents are made available. Project and program participation provides the complete remuneration of R&D expenses and leads to a capital increase as R&D is funded by government. So does public institutional funding and provides financial support for the science agents as well.

Government knows the once published kenes of all the agents and serves somehow as an autonomous agent making funding decisions. This setup also covers the process of lobbying by agents. Governmental intervention is operationalized as an evaluation oracle which judges each R&D project using a criterion that is not available to the agents ([42], pp. 175-181)[11]. As a consequence, public RTI funding is granted only if the proposals, thus the inventions of agents, partnerships or networks are accepted.

## 7 Conclusions and outlook

At later stages, particular emphasis will be laid on the assessment of the conceptual framework and the model's wider applicability while comparing the model's results with empirical data. The empirical context for the computer simulation will be the life sciences cluster in the Vienna region.

Agent-based modeling begins with assumptions about agents and their interactions and then uses computer simulations to generate "histories" that can reveal the dynamic consequences of these assumptions. With the assumptions made we can investigate how macro-scale effects measured in terms of patents, publications, and the creation of high-tech hobs arise form micro-processes of interactions among many agents. These agents represent universities, research organizations, and companies in the biotech field.

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[11] "innovation oracle"

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